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INDUSTRIAL ECOLOGY OF PROCESSING ENTERPRISES

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FOREWORD

Food production is an important component of ensuring the sustainable development of the state's economy. Ukraine has created the necessary conditions for the functioning and sustainable development of the food industry. A raw material base is being created, consumer demand for food products is increasing, and there is a sufficient labour force. Ukraine occupies a leading position in the world market for the production of certain types of food products and has every opportunity to further expand its range. In recent years, there has been a steady increase in the production of food products for both the domestic market and export.

Most food industry enterprises pollute the environment by generating large amounts of various air, water and soil pollutants. The main ones are wastewater, harmful gases and significant amounts of solid waste.

The problem with treating industrial wastewater and harmful gases is the high cost of building treatment facilities and the complex technological processes involved in waste treatment. Many countries have introduced a number of strict environmental standards for the discharge of industrial wastewater into natural water bodies and harmful gases into the atmosphere. Food industry enterprises are consumers of large amounts of drinking water, which creates the problem of generating large amounts of wastewater that requires treatment.

Most food production technologies are characterised by high specific consumption of raw materials, water, fuel, energy and other natural resources. This, in turn, leads to uncontrolled emissions of pollutants into the atmosphere, water bodies and soil, causing their contamination, which becomes an obstacle to the production of environmentally safe plant and secondary raw materials for the food industry.

Recently, the concept of «environmentally safe food products» has become widespread. Their production requires high-quality, environmentally safe raw materials and highly efficient «green technologies». To this end, environmental monitoring of food production and control of possible pollution risks are carried out.

For the environmentally friendly production of food products, it is necessary to conserve natural resources, introduce modern environmentally friendly technologies, ensure the restoration of natural resources, improve the processing of raw materials and the disposal of production waste, and improve methods for processing wastewater and waste and the use of processing products.

When training food technology specialists, it is important to study the impact of processing plants on the environment, as well as the practical application of modern wastewater treatment methods. The discipline «Industrial Ecology of Processing Enterprises» is a fundamental basis that provides students with the necessary knowledge, skills, abilities and competencies required for the proper handling of waste, environmental protection, and the development and implementation of effective methods for preventing environmental pollution.

The textbook «Industrial Ecology of Processing Enterprises» corresponds to

the course curricula for students in both full-time and accelerated programs, namely «Industrial Ecology of Processing Enterprises», «Industrial Ecology of Meat Processing Enterprises» and «Industrial Ecology of Fish Processing Enterprises», which are part of the 181 «Food Technology» program.

The acquisition of competencies by students in the process of studying the discipline involves: knowledge and understanding of the basic concepts, theoretical and practical problems in the field of food technology; understanding of professional activities; the ability to conduct research in specialised laboratories to solve applied problems; a commitment to environmental protection; the ability to design new or modernise existing production facilities; the ability to develop draft regulatory documentation using the current legislative framework and reference materials; the ability to organise the waste disposal process and ensure the environmental cleanliness of production.

The textbook may also be useful in training master's students in the specialty "Food Technology", teachers and postgraduate students, as well as specialists in various fields of the food industry who address issues of the impact of food enterprises on the environment and the greening of production.

When writing individual sections of the textbook, the authors took into account their many years of experience teaching the discipline at leading departments of universities in Ukraine and abroad.

Thus, individual sections of the textbook "Industrial Ecology of Processing Enterprises" were written by:

Chapter 1 – by professor M. Zakharenko;

Chapter 2 – by professor L. Bal-Prylypko;

Chapter 7 – by professor N. Slobodyanyuk;

Chapter 6 – by associate professor V. Poliakovskyi;

Chapter 3 – by associate professor V. Mykhalska;

Chapter 5 – by professor L. Shevchenko;

Chapter 4 – by associate professor L. Chepil and senior lecturer I. Stetsiuk.

The textbook «Industrial Ecology of Processing Enterprises» has been prepared in accordance with the curriculum of the discipline. It covers issues related to the sources of waste generation, accumulation and removal from production workshops and domestic premises, their physical and mechanical properties and chemical composition, modern methods of sanitary and hygienic assessment of waste, systems and means of transportation, storage, processing and safe disposal.

1.1. Energy conservation

The food industry is a major consumer of energy resources (electricity, heat from the combustion of natural gas and fuel oil, water vapour generated in boiler rooms, etc.). These are used for both technological processes and auxiliary technological operations (washing equipment and containers, premises, etc.). Efficient use of energy saves natural resources and reduces emissions of all harmful substances.

The development of effective energy saving schemes should primarily include the development of a legislative and regulatory framework to improve prices and tariffs, encourage investment and demonstrate a positive impact on the environment.

To implement such a scheme, it is necessary to develop and introduce energy conservation standards that are as consistent as possible with international standards; introduce administrative responsibility for the irrational use of resources; improve technological production processes; increase the use of secondary resources and materials; modern devices for regulating and consuming natural gas, electricity, heat energy and water in enterprises; and create automated energy metering systems.

In the process of implementing all these measures, the introduction of environmental management with energy audits of food enterprises is of great importance. The technological re-equipment of each enterprise requires a comprehensive approach, which is determined by the optimal balance of technical, environmental and economic indicators. To this end, energy conservation measures should include:

- automated systems for regulating and controlling technological processes;
- the use of non-traditional and renewable energy sources, especially biogas, which can be obtained simultaneously with wastewater treatment;
- regulation of the operation of energy systems (compressors, ventilation units, pumps, etc.);
- use of waste heat from power transformers and autotransformers;
- use of modern efficient electric motors, economical lighting systems, stabilisers and AC regulators. To conserve heat, it is necessary to:
- automate heating stations;
- adjust the hydraulic and temperature regimes of heating and ventilation systems;
- introduce storage heating systems and temperature controllers;
- utilise the heat from waste gases from secondary energy resources;
- use low-potential heat, in particular with the help of heat pump installations;
- improve the thermal insulation of premises and buildings using new, effective thermal insulation materials, structures and equipment.

Fuel can be saved by:

- utilising waste gases from boiler rooms;
- automating the operation of boiler rooms and boiler houses;
- using the heat from waste gases to heat the air used for combustion;
- using biogas, which can be obtained from biological wastewater treatment facilities;
- using secondary resources and waste from other industries as fuel;
- utilise the heat from the combustion products of gas turbine units at compressor stations and excess pressure.

An important issue in food production is the reuse of containers and packaging, which would significantly reduce the consumption of primary raw materials for their manufacture. Particular attention should be paid to the storage of manufactured products so that their quality is not reduced during transportation and sale to consumers.

1.2. Environmental management

For the rational consumption of natural resources and improvement of the environmental situation in Ukraine, a concept of safety for the population and economic facilities has been created, which is reflected in the Resolution of the Verkhovna Rada of Ukraine ***"On the main directions of Ukraine's state policy in the field of environmental protection, use of natural resources and ensuring environmental safety"*** dated 5 March 1998 No. 188/98. It provides for the introduction of the latest technologies for environmental protection and mandatory educational work among the population.

Effective resolution of the whole range of issues related to the production of environmentally safe food products and the elimination or reduction of the negative impact of gas and smoke emissions into the atmosphere, wastewater discharges and production waste on the environment and human health is only possible on the basis of measures provided for in the national program for the greening of the food industry (hereinafter referred to as the Program). It must take into account the state of the country's economy and the prospects for the development of the food industry.

The development of this Program is driven by the need for scientific research and the economic efficiency and technological complexity of most measures for environmentally friendly production and manufacturing of environmentally safe food products.

The state customer of the Program should be the central executive authority responsible for ensuring environmental safety and protection of the natural environment. The term of the Program is five years.

The aim of the Program should be the production of environmentally safe food products, the rational use of natural resources, the prevention of their harmful impact on the environment, the promotion of sustainable economic development of the country and the harmonious coexistence of humans and the natural environment.

The Program should provide for the following main tasks:

- identifying the main directions for the comprehensive processing of raw materials and the rational use of natural resources with minimal generation of unused and dispersed waste that pollutes the environment;
- developing and implementing program measures for the consistent reduction of waste volumes through the introduction of low-waste technologies and closed-loop processes;
- restructuring production (where possible);
- utilising, regenerating, neutralising and disposing of production waste;
- transformation of waste into non-traditional energy sources (biogas, environmentally friendly fuel for internal combustion engines, etc.), biofertilisers and other useful products.

Now that humanity is on the brink of an environmental catastrophe that threatens the existence of human civilisation, there is no more important task than overcoming the environmental crisis. Realising this, in 1992, at a forum in Rio de Janeiro, the world's states adopted the document «Agenda for the 21st Century», which contains a program for the transition to a new model of development. To this end, along with the tasks of building a constitutional state and implementing socio-economic reforms, we need to green all anthropogenic activities, including food production. Solving such a grandiose task is possible only if all members of society in general, and above all leaders of all ranks (from the president of the country to the ordinary worker of the enterprise) in particular, develop environmental awareness and ecological thinking.

It is necessary to implement and comply with the standards DSTU ISO 14001-97 and DSTU ISO 14004-97, which establish requirements for the design and application of environmental management systems. These standards are intended to ensure optimal environmental conditions for humans and their environment, as well as nature management. They must be implemented by food industry enterprises if they care about their development prospects, market expansion, increased competitiveness, integration into the global and European economic spaces, and the future of our independent democratic Ukraine. This requires the application of environmental management in all enterprises.

An environmental audit should be used to establish the actual environmental situation at each enterprise in particular and in the food industry in general. At the same time, it is necessary to carry out environmental certification of enterprises and develop a plan of measures to optimise technological processes in order to minimise the consumption of natural resources and improve the environmental situation at the enterprise in particular and in the region in general.

Questions for discussion and self-assessment

1. What waste is generated in food production?
2. What problems arise in the process of producing environmentally safe food products?
3. What are the environmental problems of water supply in the food industry?
4. Name the main environmental problems of wastewater disposal in the food industry.
5. Formulate the main problems of energy conservation in the food industry.
6. Which production processes require electricity?
7. What role does scientific research play in the development of energy conservation program?
8. What is the essence of raw material reuse?
9. What are the environmental management issues in the food industry?
10. What role does scientific research play in the development of an environmental management program?
11. Please list the regulatory documents governing environmental management.
12. What is an environmental audit?

CHAPTER 2. THE IMPORTANCE OF DRINKING WATER

The physiological importance of water:

1. plastic function of water – water accounts for an average of 65 % of an adult's body weight. 70 % of water is concentrated intracellularly, 30 % extracellularly in the blood, lymph (7 %) and intercellular fluid (23 %). The water content in bone tissue is 20 % of its mass, in muscle tissue – 75 %, in connective tissue – 80 %, in blood plasma – 92 %, and in the vitreous body of the eye – 99 %. Most of the water is a component of macromolecular complexes of proteins, carbohydrates and fats and forms gel-like colloidal cellular and extracellular structures with them. A smaller amount is in a free state;
2. participation in metabolism and energy exchange – all processes of assimilation and dissimilation in the body take place in aqueous solutions; all biochemical reactions associated with the processes of digestion and absorption of nutrients occur in an aqueous environment.
3. role in maintaining osmotic pressure and acid-base balance;
4. participation in heat exchange and thermoregulation –when 1 g of moisture evaporates from the surface of the lungs, mucous membranes, and skin (latent heat of vaporization), the body loses 2.43 kJ (about 0.6 kcal) of heat;
5. transport function – delivery of nutrients to cells by blood and lymph, removal of waste products from the body, exchange of urine and sweat;
6. as a component of the diet and a source of macro- and microelements for the body;
7. There are neuropsychiatric disorders caused by the inability to quench thirst in the absence of water or its poor organoleptic qualities. According to I.P. Pavlov's teachings on higher nervous activity, the smell, taste, aftertaste, appearance, transparency, and colour of water are stimuli that act through the central nervous system on the entire body. The deterioration of organoleptic qualities has a reflex effect on the water-drinking regime and some physiological functions, in particular, it inhibits the secretory activity of the stomach. Water with poor organoleptic properties causes a protective reaction in humans – a feeling of disgust that forces them to refuse to drink such water, even despite thirst.
8. Water is used for therapeutic purposes (consumption of mineral waters, therapeutic baths), as well as a factor in hardening (bathing, swimming, rubbing).

The domestic role of water:

1. use of water for cooking and as a component of the diet;
2. as a means of maintaining the cleanliness of the body, clothing, linen, dishes, residential, public and industrial premises, and the territory of settlements;
3. irrigation of green spaces within settlements;
4. sanitary, transport and decontamination functions of water – removal of domestic and industrial waste through the sewage system, its decontamination at treatment facilities, self-cleaning of water bodies;

5. firefighting, cleaning atmospheric pollution (rain, snow).

The economic importance of water:

1. use in agriculture (irrigation in crop and horticulture, greenhouses, poultry and livestock complexes);
2. in industry (food, chemical, metallurgical, etc.);
3. as routes for water (passenger and freight) transport.

The solubility of disinfectants depends on the mineral composition of water. Hard water quickly damages water heating equipment. Water used for hydroflushing should not contain toxic substances and pathogens of infectious and invasive diseases.

Nowadays, the role of water in the spread of infectious and invasive diseases and mass non-contagious diseases in animals and humans is undeniable. A well-established water supply is a specific measure for the prevention of intestinal infections among the population. Thus, with the help of vaccinations, it is possible to reduce the incidence of typhoid fever by 5 – 8 times, while with a centralised water supply, the incidence has decreased by 8 – 12 times.

The epidemiological and toxicological role of water:

1. water can contribute to the spread of infectious diseases as a factor in the transmission of pathogens through the faecal-oral mechanism:
2. intestinal infections of bacterial and viral etiology (typhoid fever, paratyphoid A and B, cholera, dysentery, salmonellosis, escherichiosis, tularemia, viral hepatitis A, poliomyelitis, enterovirus diseases caused by Coxsackie viruses;
3. geohelminthiasis (ascariasis, trichocephalosis, ankylostomiasis);
4. biohelminthiasis (development of broad tapeworm (diphyllobothriasis), cat tapeworm, and liver fluke larvae in the biocenoses of open water bodies);
5. diseases caused by protozoa (amoebic dysentery, giardiasis, leptospirosis, etc.);
6. as a factor in the transmission of pathogens of the skin and mucous membranes (when bathing or other contact with water): trachoma, leprosy, anthrax, fungal diseases (e.g., epidermophytosis);
7. as a breeding ground for disease vectors – mosquitoes of the genus *Anopheles*, which carry plasmodia (protozoa) that cause malaria (open water bodies).

The possibility of transmission through water of cholera, typhoid fever, brucellosis, viral hepatitis (Botkin's disease) has been proven. Pathogenic microorganisms, helminth eggs and their larvae can remain viable in water for a long time. In wastewater, the foot-and-mouth disease virus can survive for 100 days or more.

Water plays a major role in the emergence of a number of endemic diseases associated with an excess or deficiency of macro- and microelements (biogeochemical provinces). The most studied endemic diseases are associated

with a deficiency or excess of fluorine, iodine, strontium, cobalt, and copper. In the western regions of our country, there is an insufficient amount of iodine in the water (below 0.5 mg/l), which leads to an enlargement of the thyroid gland and stunted growth and development in humans and animals.

For example, in Japan, hundreds of residents of the city of Minamata were poisoned by mercury compounds that accumulated in fish, crabs, and oysters (it was found that children born to mothers poisoned by mercury were blind, paralysed, and deaf). Cadmium poisoning causes Itai-itai disease, which is accompanied by complex bone fractures.

Currently, the quality of water in rivers and lakes is changing under the influence of pesticides and mineral fertilisers used in agriculture. Waste from ferrous and non-ferrous metallurgy pollutes water bodies with heavy metal compounds, which negatively affects the self-purification of water bodies and causes fish to die.

2.1. Water impurities

Aluminum. The concentration of aluminum in surface waters ranges from 0 to 10 mg/dm^3, and in groundwater from 0 to 242.2 mg/dm^3. In most water sources, aluminum is found in concentrations ranging from tenths of a milligram to several milligrams per liter.

Studies show that aluminum is neurotoxic and can accumulate in nerve tissue. If the excretory function of the kidneys is impaired due to various diseases, aluminum can accumulate in the liver and vital areas of the brain, causing severe disorders of the central nervous system. The aluminum content in drinking water is mainly determined by its presence in coagulants used in water treatment and its content in surface waters.

Barium. In natural waters, the barium content is 0.001 – 0.01 mg/dm^3, rarely 0.1 mg/dm^3. It mainly enters water sources with wastewater. Barium is a highly toxic substance that can cause gonadotoxic, embryotoxic and mutagenic effects even at low doses. When it enters the body, it can accumulate in bone tissue. The lethal dose of barium, which enters the body in the form of chloride, for adults is 550 – 600 mg.

Beryllium. Its elevated concentrations can be observed in the groundwater of some geological provinces and in surface waters as a result of beryllium-contaminated wastewater from the aviation industry. Beryllium is a highly toxic and cumulative poison, capable of causing a wide range of long-term adverse effects.

Boron. Boron occurs in high concentrations in highly mineralised groundwater and seawater. There are some known biogeochemical provinces where boron is found in elevated concentrations in surface waters. When high concentrations of boron enter the human body through drinking water, significant disorders of the reproductive system are observed, as well as a pronounced embryotoxic effect.

Molybdenum. The molybdenum content in surface and groundwater reaches thousandths and hundredths of a milligram per litre. In areas of industrial

molybdenum ore mining, its concentration in surface waters polluted by industrial wastewater can reach 1 mg/l. An excess of molybdenum in the body leads to a disturbance in the metabolism of purine bases, which manifests itself in polyarthralgia and arthrosis (molybdenum gout).

Arsenic. The arsenic content in fresh groundwater and surface water is low, but in areas where polymetallic ores are found, it can exceed 1 mg/dm^3. Elevated levels are found in hydrometallurgical waste and TPP ash, which can cause groundwater contamination. Prolonged consumption of arsenic-contaminated water causes calluses to appear on the skin. In addition, blood vessels may be affected and tumours may develop. Lifelong consumption of water with an arsenic concentration of 0.2 mg/dm^3 results in a 5 % risk of developing skin cancer. In cases of acute arsenic poisoning, the central nervous system is affected, leading to colic, and at doses of 70 – 80 mg/dm^3, death.

Nitrates and nitrites. The use of fertilisers, the decomposition of plant and animal residues, domestic sewage, the disposal of sewage sludge in the soil, industrial discharges, and leaching from the atmosphere all contribute to the entry of nitrate and nitrite ions into water sources. The nitrate content in water is usually less than 5 mg/dm^3, but in underground surface water sources it can exceed 10 mg/dm^3.

When nitrates and especially nitrites enter the human bloodstream through drinking water, methaemoglobin accumulates, which is unable to transport oxygen from the blood to the tissues. As a result, methaemoglobinaemia develops. The presence of nitrates and nitrites in water poses a carcinogenic risk. Under certain conditions, carcinogenic nitrosamines can be formed from nitrites in the human body. The formation of nitrosamines intensifies in the case of infectious diseases of the bladder or low acidity in the stomach.

Selenium. The selenium content in surface waters is significantly lower than 10 μg/dm^3, but in some wells it can exceed 100 μg/dm^3, the consumption of groundwater with elevated selenium levels disrupts tooth enamel formation and calcium metabolism and has a negative effect on liver function. In some cases, damage to the myocardium, kidneys and pancreas is also observed.

Strontium. The strontium content in surface water is usually a few tenths of a milligram per litre and only in some provinces does it increase to several milligrams. With prolonged consumption of groundwater with elevated strontium content, children have been found to have bone tissue development disorders (delayed tooth development, etc.).

Fluoride. The fluoride content in most water sources does not exceed 0.5 mg/dm^3, but there are some geographical provinces where the fluoride content in groundwater is more than 1.5 mg/dm^3, as well as water sources with a fluoride content of less than 0.5 mg/dm^3.

Excess fluoride in drinking water (more than 1.5 mg/dm^3 leads to the development of fluorosis, one of the signs of which is the formation of spots on the tooth enamel. In addition, it can disrupt skeletal ossification in children and cause changes in the heart muscles and nervous system.

A lack of fluoride in water (with a content of less than 0.5 m/dm^3 causes the

development of dental caries – the main cause of tooth loss in adolescence and adulthood. Fluoride plays a very important role in regulating the mineral metabolism of the skeleton. At an early age, it promotes bone mineralisation, and in old age, it reduces the degree of age-related bone demineralisation. If water with a fluoride concentration of more than 3 – 6 mg/dm³ is consumed, skeletal deformation is observed.

Lead. In unpolluted lake and river waters, the lead content does not exceed 0.01 mg/dm^3. However, in areas where polymetallic ores are found, its content in groundwater can increase significantly.

In high doses, lead is a cumulative metabolic poison with general effects. There are known cases of severe lead poisoning from drinking water with elevated levels (0.6 – 2.0 mg/dm³). Poisoning is accompanied by intestinal cramps, exhaustion and death. This metal has a high cumulative capacity, accumulates in the bones, causes erythropoiesis disorders, affects the nervous system and kidneys, and leads to early atherosclerosis. At a concentration of 0.1 mg/dm^3 in drinking water, the body accumulates 50% of the absorbed lead, and its content in the blood reaches a limit of 0.025 mg/dm^3. Symptoms of acute poisoning include rapid fatigue, abdominal discomfort, anaemia, and, in children, behavioural abnormalities.

Iron. Surface water sources may contain up to 8 – 10 mg/dm^3 of iron, mainly in the form of complexes with humic compounds. A high iron content in drinking water is undesirable as it negatively affects its organoleptic properties. Water with a high iron content tastes unpleasant, has a brown colour, and forms concretions in pipes, which create resistance to water flow and damage water supply fittings.

Manganese. In surface waters, the manganese content can reach 8 mg/dm^3, in groundwater – up to 0.7 mg/dm^3; if the latter is associated with manganese deposits, its content can increase to 300 mg/dm^3. According to WHO data, manganese content in drinking water up to 0.5 mg/dm^3 does not harm human health. However, water with such manganese content has a metallic taste and stains fabrics during washing.

Copper. The concentration of copper in natural waters is tenths of a milligram per litre. However, the copper content in drinking water may increase due to its transfer from fittings and equipment. In small concentrations, copper has an unpleasant astringent taste, which limits its content in drinking water.

Zinc. The zinc content in surface water sources usually does not exceed 0.01 and 0.05 mg/dm^3 in groundwater, but in tap water it can increase to 2 mg/dm^3 due to leaching from galvanised pipes. Elevated zinc content negatively affects the organoleptic properties of drinking water. A metallic taste is not noticeable at concentrations below 5 mg/dm^3.

Cadmium. Normally, the cadmium content in natural waters is 0.05 – 1 μg/dm^3, but in cadmium provinces it reaches 10 μg/dm^3. Due to the pollution of natural waters with wastewater, its content can increase to 0.2 – 4 mg/dm^3. Cadmium is an extremely toxic element. Its toxicity at a concentration in water of about tens of micrograms per litre manifests itself in severe kidney damage and associated hypertension. Cadmium also has a

gonadotoxic effect.

Chromium. Industrial wastewater discharged into natural water bodies can contaminate them with chromium. Chromium (VI) has toxic properties. The adverse effects of chromium on the human body include damage to the kidneys and liver, and the development of gastric and duodenal ulcers. In addition, it has carcinogenic and mutagenic effects.

Nickel. The nickel content in surface waters reaches 1 mg/dm^3, and in some groundwater – up to 0.13 mg/dm^3. Due to the pollution of natural waters with industrial wastewater, its concentration can increase to 275 mg/dm^3. Excessive intake of nickel into the human body disrupts biochemical processes at the cellular and subcellular levels. Prolonged contact with nickel aerosols leads to the development of lung and stomach cancer.

Mercury. In polluted water bodies, the mercury content ranges from 0.01 to 0.5 μg/dm^3. In rivers polluted with wastewater, its content can be hundreds and thousands of micrograms per litre. Inorganic mercury compounds quickly accumulate in the kidneys and enter the bloodstream. Mercury poisoning mainly manifests itself in the form of neurological and renal disorders. Inorganic mercury compounds typically cause kidney and liver damage, while organic compounds are neurotoxic and embryotoxic. Along with its general toxic effect, mercury causes gonadotoxic and mutagenic effects and disrupts cholesterol metabolism.

Cyanides are extremely toxic compounds containing the CN^-ion. Technogenic sources of cyanides include the production of coke, polymers, precious metals, electroplating, and some organic synthesis technologies. A single dose of 50 – 60 mg of cyanide is usually fatal to humans. Cyanide at levels of 2.9 – 4.7 mg per day is not harmful to humans due to the high efficiency of the body's detoxification system. Higher doses can be fatal. The acceptable daily intake of cyanide for humans is 8.4 mg.

Dry residue and water hardness

Dry residue affects the taste of drinking water. Water is suitable for consumption if its dry residue content is up to 1000 mg/dm^3. However, if the dry residue content is low, the water may have an unpleasant taste. Drinking water with high hardness has an adverse effect on the cardiovascular system. Consumption of such water can lead to the development of urolithiasis.

Suspended substances affect the organoleptic properties of water, promote the sorption of viruses and their transfer by water flow. Viruses that enter the body with suspended particles have a negative impact on epidemic safety (Fig. 2.1).

Organic substances of natural origin – humates, amines, etc. – negatively affect the organoleptic properties of water (smell, taste, colour, foaming ability, etc.).

Pesticides. Pesticides found in water include chlorinated hydrocarbons and their derivatives, soil insecticides, etc. The concentration of DDT (dichlorodiphenyltrichloroethane) in surface waters can vary between 0.01 and 0.84 μg/dm^3. It mainly affects the nervous system and liver. The conditionally acceptable daily intake for humans is no more than 0.005 mg/kg of body weight.

The pesticide *dieldrin* is deposited in fatty and muscle tissue, the liver and the brain. Its daily accumulation in the fatty tissue of a person weighing 70 kg can reach 0.01 – 0.35 μg/kg of body weight. Dieldrin affects the nervous system. The established daily intake of aldrin and dieldrin, either separately or in combination, is 0.0001 mg/kg of body weight.

Chlordane is a broad-spectrum insecticide from the group of polycyclic chlorinated hydrocarbons, which has been widely used recently to control termites and soil insects, for treating orchards and growing corn. Chlordane has been found in surface water (up to 8 μg/dm^3) and rainwater. It occurs in drinking water in insignificant amounts. The acceptable daily intake of chlordane for humans is 0.001 mg/kg of body weight, and the recommended level of its content in drinking water is 0.3 μg/dm^3.



Fig. 2.1. Suspended substances in water [49]

Polycyclic aromatic hydrocarbons (PAHs) are poorly soluble in water, but have a high sorption capacity on clays and other bottom sediments, which causes them to appear in large quantities in water. PAHs cause various damage to the skin and its sebaceous glands, bone marrow and lymphatic system. There are 14 known carcinogenic PAHs. The strongest carcinogen is benzopyrene. Polychlorinated surfactants – dibenzo-n-dioxins (PCDDs), dibenzofurans (PCDFs) and biphenyls (PCBFs) – pose a great danger to health and are extremely toxic. The estimated median lethal doses of dioxins for humans are measured in hundredths of a milligram per 1 kg of body weight. In the case of prolonged exposure to very low doses, they can cause carcinogenic, teratogenic, gonadotoxic and immunosuppressive effects.

These compounds are extremely persistent and enter water bodies with wastewater from the production of chlorophenols and their derivatives. They may enter groundwater at industrial waste disposal sites.

Trihalomethanes. During water chlorination, halogen-containing compounds are formed, the quantitative and qualitative composition of which depends on the

content of humic and fulvic acids, phenols, etc. in natural waters. The effect of halogen-containing compounds (HCC) is manifested in the formation of malignant tumours, genetic diseases, etc.

Synthetic surfactants (SSAs) are widely used in industry and everyday life. Therefore, large quantities of them enter water bodies with wastewater. SSAs impair the organoleptic properties of drinking water (unpleasant taste and foaming).

Petroleum products have an adverse effect on the organoleptic properties of water: the appearance of a specific odour and rainbow spots on the surface. The toxic effect of petroleum products is insignificant at the concentrations at which they occur in natural water, into which they enter with wastewater.

Radioactive substances. Up to 250 radioactive isotopes of anthropogenic origin enter the environment as a result of the operation of nuclear facilities. Radionuclides, which enter the human body along with water, air and food, cause cancer, congenital disabilities, a decrease in immune system function and increase the overall morbidity of the population.

Microorganisms, bacteria and viruses develop in the aquatic environment, which can cause brucellosis, dysentery, typhoid fever, paratyphoid fever, jaundice, acute gastroenteritis, cholera, tularemia, anthrax, poliomyelitis, etc. Contamination with pathogenic bacteria is usually determined by the presence of intestinal bacilli in the water.

2.2. The impact of water impurities on human health

Both the microbiological and chemical composition of drinking water have a significant impact on human health. The microbial factor often manifests itself in the form of epidemic outbreaks of disease. The impact of the chemical factor may not be immediately apparent, but only after some (sometimes very long) time. This is due to low concentrations of contaminants that are not capable of causing acute poisoning, as well as their insignificant absorption through the skin during hygiene or health procedures (shower, bath, swimming pool). Children are at increased risk of intoxication (especially in the first year of life) due to the greater absorptive capacity of children's skin and the higher toxicity of substances to the child's body.

Many substances that enter water sources with industrial wastewater can cause allergic reactions when contaminated water comes into contact with human skin.

Chemicals alter the organoleptic properties of water – its smell, taste, colour, turbidity, ability to form foam and films, etc. The simultaneous intake of several substances with water can lead to pathological effects that are not characteristic of each of them individually (combined effect). The suitability of water for consumption is a complex task that cannot be solved unambiguously on the basis of chemical analysis alone. It must be solved by technologists and hygienists. Due to the complexity of the mechanism of interaction between chemicals and the body, the intensity of their action and quantitative indicators are usually determined experimentally on warm-blooded animals.

The maximum permissible concentration (MPC) of a chemical substance in water is the maximum concentration at which human consumption of water for drinking and domestic purposes throughout their lifetime directly or indirectly (due to changes in the organoleptic properties of water) does not cause deviations in the state of the organism's that go beyond adaptive physiological reactions and are detected by modern research methods immediately or in the long term in the lives of current and future generations, and does not worsen the hygienic conditions of water use by the population. During the experimental justification of hygienic MPCs in drinking water, two important areas of adverse effects are considered: the possibility of toxic effects and the impact on the organoleptic properties of water.

It is extremely important to regulate the chemical composition of water used in food industry processes. At the same time, it is necessary to take into account the possibility of intoxication of consumers of products made with water with a high concentration of contaminants (higher than hygienic standards), as well as changes in the organoleptic characteristics of the product or the impact on the course of technological reactions. The chemical composition of water is particularly important in the manufacture of beverages. Here it is important to control indicators such as hardness, mineralization, transparency, microelement composition, etc., which are determined by the specifics of the technology or special requirements for the consumer properties of the product.

Bacterial contamination is particularly dangerous. Pathogenic bacteria can be transmitted through the consumption of contaminated water and food, contact with sick people or animals, and airborne droplets. Drinking water containing excessive amounts of organisms such as *Pseudomonas, Flavobacterium, Acinetobacter, Klebsiella* and *Serratia* can cause a wide variety of infectious lesions of the skin and mucous membranes, eyes, ears and nasopharynx. The infectious dose depends on the age, nutrition and general health of the person.

Intestinal viruses transmitted through drinking water can cause a variety of syndromes, including rash, fever, gastroenteritis, myocarditis, meningitis, respiratory diseases and hepatitis. Contamination of drinking water with sewage can cause two diseases that take the form of epidemics: gastroenteritis and infectious hepatitis.

Of all intestinal protozoa that are pathogenic to humans, three can be transmitted through drinking water: *Entamoeba histolytica, Giardia Spp.* and *Balantidium coli.* These organisms are the aetiological agents of amoebiasis (amoebic dysentery), giardiasis and balantidiasis, respectively. All of them are associated with outbreaks of diseases caused by drinking water contamination. Common clinical manifestations are gastroenteritis with symptoms ranging from mild diarrhoea to transient dysentery with bloody diarrhoea. The most common complication is liver abscess.

Drinking water may contain large numbers of helminth eggs and larvae. Two groups of helminths are more closely associated with water supply: those that are transmitted exclusively by ingestion of their intermediate hosts – infected copepods (group I), and those whose cercariae directly infect humans (group II).

Group I includes *Dracunculus medinensis* – guinea worm, a thread-like parasite of humans, and *Spirometra.* Guinea worm, or dracunculiasis (dracunculiasis) – one of the main diseases leading to disability. A much less common disease is sparganosis, in which larvae located under the skin cause the formation of ulcers. Particularly dangerous consequences are observed in cases of eye damage.

Group II includes *Schistosoma, Ancylostoma, and Necator*. The *Schistosoma* genus is the most significant in this group. Infections caused by it occur when contaminated water is used for domestic purposes, bathing, or washing. Human schistosomes cause primary lesions mainly in the liver, stomach, and around the bladder. However, the most serious consequences are associated with secondary damage to the upper urinary tract, bladder cancer and liver fibrosis.

Free-living organisms in water supply systems, along with plankton and macroscopic invertebrates, complicate water purification processes, release substances toxic to humans, host pathogenic organisms and form organic substances that can be converted into halogenated organic compounds during chlorine disinfection. Large invertebrates can reduce the efficiency of the distribution network and interfere with the supply of water to consumers.

Some toxic substances produced by certain algae have a negative impact on human health. Poisonous species occur in two groups of algae: golden *(Xanthophyta)* and blue-green *(Cyanophyta)*. Toxic blue-green algae are the most complex problem in water treatment. Toxic compounds released by algae can enter water treatment facilities and cause outbreaks of gastroenteritis. Algae can cause the formation of trihalomethanes, which are produced during the chlorination of water, which is used to destroy pathogenic agents and create a protective barrier against pathogenic agents entering the drinking water distribution system.

Questions for discussion and self-assessment

1. The physiological importance of water.
2. The economic and domestic role of water.
3. The economic significance of water.
4. The epidemiological and toxicological role of water:
5. Which elements in water are associated with endemic diseases in humans?
6. Name the impurities in water.
7. Indicate the sources of impurities in water.
8. What regulatory documents regulate the content of impurities in water?
9. How do nitrates and nitrites affect the body?
10. Indicate the sanitary indicators of water.
11. What is dry residue in water?
12. Which salts cause hardness in drinking water?
13. How do pesticides get into drinking water?
14. For what purpose are synthetic surfactants used in industry and everyday life, and what effect do they have on water?

15. How do radioactive substances get into drinking water and how can they be removed from water?
16. Do chemical indicators affect the organoleptic properties of water?
17. How does water pollution affect human health?
18. Which intestinal protozoa are pathogenic to humans?
19. Identify sources of water contamination with helminth eggs and larvae.
20. What diseases arise as a result of microbiological contamination of water?
21. What does the term «maximum permissible concentration (MPC) of a chemical substance in water» mean?

CHAPTER 3. SANITARY AND HYGIENIC REQUIREMENTS FOR WATER SUPPLY SOURCES

(*Water Code of Ukraine, Council Directive 79/869/EC, Council Directive 78/659/EC, Council Directive 77/795/EEC, Council Directive 77/795/EEC, DSTU 17.1.3.05-82, DSTU 17.1.3.06-82, DSTU 17.1.3.10-83, DSTU 2761-84)*

According to *the Water Code of Ukraine*, water bodies *of national importance* include:

1) internal sea waters and territorial sea;
2) groundwater, which is a source of centralised water supply;
3) surface waters (lakes, reservoirs, rivers, canals) located and used in more than one region, as well as their tributaries of all orders;
4) water bodies within the territories of the national nature reserve fund, as well as those classified as therapeutic.

Water bodies *of local importance* include:

1) surface waters located and used within one region and not classified as water bodies of national importance;
2) groundwater that cannot be a source of centralised water supply.

All waters (water bodies) on the territory of Ukraine constitute its water fund.

The water fund of Ukraine includes:

1) surface waters:
   - natural reservoirs (lakes);
   - watercourses (rivers, streams);
   - artificial reservoirs (reservoirs, ponds) and canals;
   - other water bodies;
2) groundwater and springs.
3) internal sea waters and territorial sea.

Depending on the source of water supply, water is divided into:

- atmospheric;
- surface;
- groundwater.

Atmospheric water

Atmospheric water falls to the Earth's surface in the form of rain, hail, snow, dew and fog. It is characterised by a high content of gases (nitrogen, oxygen and carbon dioxide). Due to their presence, atmospheric water has an acidic reaction, which gives it an unpleasant taste. It is weakly mineralised and contains a large amount of dust and microorganisms. It is rarely used for domestic purposes and only in areas where surface and underground water is scarce.

As *rainwater* passes through the atmosphere (a 50 mg drop washes 16 liters of air as it falls), it mechanically washes out various impurities in its path, becomes enriched with dust and bacteria, and absorbs various gases. If we take 1 litre of rainwater, we can find impurities contained in 30,000 liters of air in it. It

is weakly mineralised, contains few soluble gases, and therefore is soft, tasteless and rots quite easily.

It is therefore clear that the purity of rainwater depends on a number of factors, namely: the sanitary and ecological condition of the area under which the cloud formed, atmospheric pollution, etc. It is known that sulphur and nitrogen compounds react with water in the atmosphere and turn into acids. These acids fall to the ground in the form of so-called acid rain. Today, given the ecological state of the atmosphere, almost every rain can be considered "acidic".

Surface sources (*Water Code of Ukraine*) include ponds, rivers, lakes, reservoirs, and seas. Since they are subject to pollution, water from these sources is not always suitable for drinking and use in the processing industry without prior treatment.

Seawater is used only in cases of fresh water shortage in industrial water supply systems, for example, at ore processing plants and metallurgical plants. Seawater is used for drinking water supply in isolated cases, after artificial desalination.

Groundwater **is** water located below the earth's surface in the rock strata of the upper part of the earth's crust in all physical states. Groundwater is divided into "surface water", soil (unconfined) and artesian (confined) water, which lies below the level of the earth's surface.

When choosing a water source, preference is usually given to groundwater that is not contaminated by surface runoff. In most cases, groundwater is not purified. Hygienic requirements for water sources are set out in *DSTU 7525:2014. Drinking water. Requirements and methods of quality control*.

The standard stipulates that the choice of a source of domestic and drinking water supply must be agreed with the sanitary and epidemiological service. If there is an insufficient amount of groundwater, its quality is unsatisfactory, or its use is economically unfeasible, water is taken from surface sources, purified and disinfected. Industrial water supply requires large quantities of water of lower quality than domestic and drinking water. Therefore, water from surface sources is preferred for these purposes.

3.1. Surface water

Surface water (*Water Code of Ukraine*) – water from various water bodies located on the earth's surface.

Water intake from surface sources is usually located above the settlement served by the water supply system, on a section of the river with a stable channel and sufficient depth.

A special clause *of the State Sanitary Norms and Rules "Hygienic Requirements for Drinking Water Intended for Human Consumption" (DSanPiN 2.2.4-171-10)* establishes that the content of chemical compounds in water entering a reservoir with industrial, agricultural and domestic pollution is regulated within

the limits specified in the list of maximum permissible concentrations of chemical substances in the water of water bodies. The list, approved by the Ministry of Health, currently includes standards for more than 800 compounds.

River water

Depending on the catchment area of the basin, rivers are divided into large, medium and small.

Large rivers are those located in several geographical areas and have a catchment area of more than 50,000 square kilometres (Fig. 3.1).



Fig. 3.1. The Dnieper – Ukraine's main waterway

Medium rivers are those with a catchment area of 2 to 50 thousand km² (Fig. 3.2).

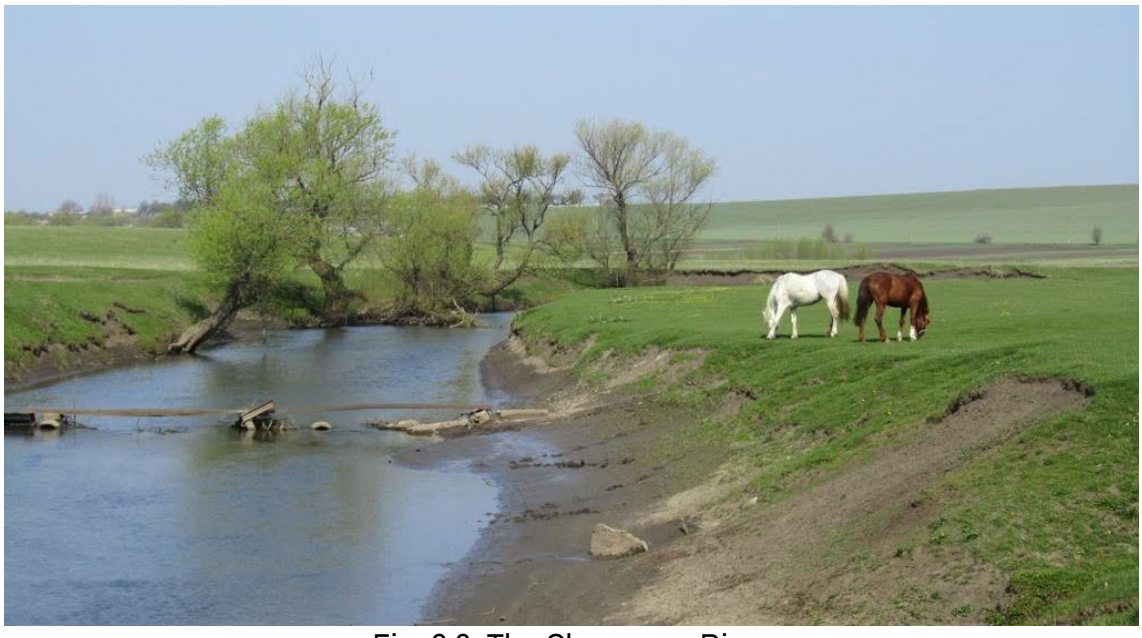


Fig. 3.2. The Chornyava River

Small rivers have a catchment area of up to 2,000 km² (Fig. 3.3).



Fig. 3.3. The Middle Hovtva River

River water is a mixture of rainwater, swamp water, lake water, spring water, and water from melting snow and ice (mountain rivers). Rivers absorb surface runoff from the catchment area, i.e., the territory within which they are fed. During spring floods, storms and rainy floods, river water is turbid and contains a lot of organic matter.

The quality of river water varies greatly depending on the season. It is most polluted in spring and autumn due to increased atmospheric precipitation and surface water runoff. In winter, river water is less polluted because reservoirs that are under ice effectively lose their surface supply. Water in rivers that are fed mainly by groundwater is much cleaner than in rivers that depend on surface runoff. The composition and quality of river water are influenced by the condition of the banks and the nature of the terrain adjacent to the river (Fig. 3.4).

If the latter flows through large settlements and industrial areas or is contaminated with sewage and other pollutants, river water is often hazardous from a sanitary point of view. Rivers that flow far from settlements are much less polluted and have better water quality.

In general, river water contains few mineral salts, and the amount of organic substances and microorganisms depends on the degree of pollution of the water body.



Fig. 3.4. The Dniester River

Lake water

Lakes are bodies of water that are mostly stagnant. The composition and quality of lake water largely depend on the nature of the shores, the size and depth of the reservoir, the season, the population of the area, etc. The chemical and bacteriological composition of lake water is basically similar to that of river water. However, due to the slow flow or lack thereof, lake water is better settled.

Large deep lakes fed by spring water, as well as lakes located far from densely populated areas and industrial enterprises, in most cases have water that is quite suitable for drinking purposes. In shallow stagnant lakes, the water quality is low (Fig. 3.5).



Fig. 3.5. Lake Yalpug (Odessa region)

Pond water

Ponds are artificial reservoirs formed in natural or specially dug depressions with a capacity of no more than 1 million m^3. The water in them is mainly stagnant

or has a slight current. Water enters ponds from rivers, streams, springs, or they are fed only by atmospheric precipitation (Fig. 3.6).

Ponds are the least suitable sources of water supply for industrial enterprises due to their pollution, blooming, overgrowth with aquatic vegetation, silting, salinisation, etc. In reservoirs with stagnant water, with the mass development of blue-green algae plankton, the water turns greenish or brownish in colour and, due to the mass death of algae, acquires an unpleasant smell and taste. Such water is toxic to humans.

Pond water is heavily contaminated with bacteria. Its coli titre is 0.1 – 0.001 ml with hundreds of thousands of colonies per 1 ml of water. The water in ponds located in areas of human settlements and livestock farms is often contaminated with organic and mineral substances and is hazardous from a sanitary point of view.

Salmonella, leptospira, cholera vibrio and paratyphoid pathogens are often found in stagnant waters. Such reservoirs pose a great danger, since bacteria from the salmonella group not only remain viable for a long time, but can even multiply at the appropriate temperature.



Fig. 3.6. Pond

Reservoirs or dams

A reservoir ***is*** an artificial water body with a capacity of more than 1 million m³, built to store water and regulate its flow. These reservoirs are formed by damming river valleys, lake outlets, mountain channels and gorges.

They are mainly replenished with water during the spring floods. In the absence of pollution, the water in reservoirs is of satisfactory quality and meets sanitary requirements (Fig. 3.7).



Fig. 3.7. Reservoir

3.2. Groundwater

Groundwater is divided into the following types according to the conditions of occurrence and feeding of aquifers:

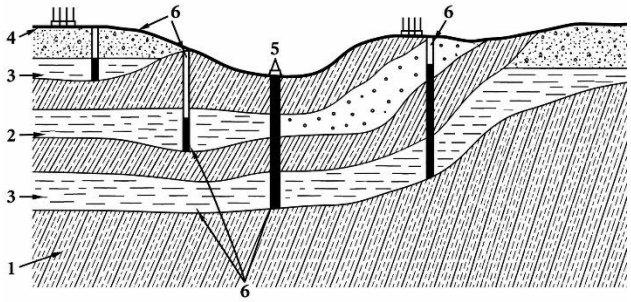
- «surface water»;
- free-flowing (unconfined);
- interlayer (pressurised) groundwater, covered by impermeable rocks;
- artesian.

Surface water

Surface water is located in the upper (2 – 3 m) layer of soil, accumulating above the first impermeable layer, and its depth depends on the depth of this layer. Depending on the season, these waters are at different depths from the surface, and during droughts they can disappear completely. Part of these waters forms the so-called soil solution, which fills the capillary spaces between soil particles, forming a hydration layer.

Since *the* upper *water table* is not covered by impermeable rocks, it is subject to atmospheric pressure and external climatic influences. Water can easily be contaminated by surface runoff: the deeper the groundwater lies, the less contaminated it is. The upper water table is connected to surface water bodies and feeds them with its waters.

The upper water table is formed as a result of atmospheric precipitation seeping through water-permeable rocks (sand, sandy loam, loam) to layers of water-impermeable rocks. The place where groundwater is fed coincides with the place where it spreads (Fig. 3.8).



1 – impermeable rocks; 2 – artesian water horizon; 3 – interlayer unconfined water horizon; 4 – groundwater horizon; 5 – groundwater recharge zone; 6 – unconfined wells; 7 – artesian well; 8 – pressure well; 9 – groundwater distribution zone.

Fig. 3.8. Groundwater distribution diagram

Groundwater is located under the first impermeable layer, which lies at a depth of at least 7 m and no more than 2 – 3 km (sometimes up to 6.5 km). It can be found in several aquifers and can be *unconfined* or *confined*. Groundwater is used to supply water to populated areas. Water located at a depth of more than 15 m (in the third or even deeper impermeable layer) is also called deep groundwater.

Pressurised water

These waters are always protected from surface contamination by an impermeable upper layer. Their formation is associated with the specific conditions of occurrence of aquifers. Artesian waters fill the entire thickness of the water-permeable rock and are under pressure (see Fig. 3.8); the greater the pressure, the higher the level to which the water can rise in the well. Pressurised water is also called self-flowing, gushing or artesian water, and the areas where it is found are called artesian basins. The source of pressurised water is sometimes located hundreds of kilometers away from where it is found.

Artesian water

Named after the French province of Artois, where it was first extracted in the 15th century, it is the best source of water supply from a hygienic point of view. It is found in large areas. Aquifers often have several aquifers (tiers) located at different depths from the surface. Ukraine has powerful aquifers with good-quality water: Sarmatian, Buchak, Jurassic, Cenomanian, Meotic, Pontic, etc.

The choice of location for water catchments for the capture of groundwater is determined by the thickness and depth of the aquifer, the direction of the underground flow and sanitary conditions.

The following structures are used to utilise groundwater:

- horizontal water intakes that intercept the soil flow when the aquifer is located at a depth of 6 – 8 m and has a thickness of 2 – 5 m;
- shaft wells – when the aquifer is located at a depth of 10 – 20 m, and sometimes up to 30 m;
- tubular wells – when groundwater lies at a depth of more than 20 – 30 m.

Sources

Groundwater (soil and interlayer) sometimes rises to the surface on its own, forming gushing springs.

Sometimes groundwater flows to the surface in the form of springs, which greatly facilitates its use for water supply. Non-pressurised groundwater comes to the surface through descending springs, while pressurised groundwater comes to the surface through ascending springs.

The quality of such water depends on the source of the aquifer and the design of the catchment.

In most cases, spring water, both groundwater and interlayer, has high sanitary and hygienic qualities and is a perfectly suitable source of water supply.

However, only those sources that flow all year round with constant force and belong to an aquifer that is deeply buried and well protected from pollution are considered reliable in sanitary terms.

In some cases, springs are fed by groundwater. The sanitary assessment of springs should be made on a case-by-case basis based on the results of observation and physical and chemical studies.

Questions for discussion and self-assessment

1. Which water bodies are of national importance?
2. Which water bodies are of local importance?
3. Which water bodies belong to the water fund of Ukraine?
4. Sanitary and hygienic requirements for atmospheric waters.
5. Classification of atmospheric waters.
6. Sanitary and hygienic requirements for surface sources.
7. Classification of surface waters.
8. Sanitary and hygienic requirements for groundwater.
9. Classification of groundwater.
10. What is the purpose of reservoirs?
11. What is surface water?
12. What is artesian water?
13. Which water sources are best for domestic and industrial use?
14. What factors determine the properties of water?
15. What regulatory documents govern water quality?

FCHAPTER 4. POLLUTANTS FROM INDUSTRIAL ENTERPRISES AND THEIR DISPOSAL

One of the most significant problems in food production is the preparation and use of high-quality water, which is consumed as a raw material reagent, for washing raw materials and equipment, transporting heat carriers, etc. For example, the production of 1 tonne of sugar requires 60000 litres of water, 1 tonne of pressed yeast requires 100000 litres, 1000 litres of alcohol requires almost 50000 litres, and 10 litres of beer requires about 15 – 20 litres of water. At meat processing plants, 1 tonne of meat accounts for 6.9 – 8.9 m^3 of wastewater. In the fish processing industry, fish meal and fish oil factories discharge 1 – 4 m^3 of wastewater per 1 tonne of raw materials. The total amount of wastewater discharged into the sewer system can reach 30 – 50 thousand litres per 1 tonne of raw materials. For 1 litre of processed milk, under conditions of economical consumption, 1 – 2 litres of water are consumed, and at some factories even up to 8 litres.

The food industry mainly consumes drinking water, which is prepared mainly at municipal water treatment plants, sometimes at the enterprises themselves. Considering that most water treatment plants use outdated technologies that do not ensure the production of water of adequate quality, especially in terms of the content of soluble impurities (nitrates, pesticides, heavy metals, chlorides, sulphates, etc.), since their removal is not provided for by generally accepted technology, it can be argued that, for the most part, water of unsatisfactory quality is used for the production of food products.

Due to the large amount of water used in food production technology, a large amount of polluted wastewater is generated. The composition of wastewater generated by food industry plants is shown in Table 4.1.

As can be seen from Table 4.1, wastewater is mainly contaminated with organic impurities, which are residues of raw materials and products of their transformation. Wastewater and other waste are currently mainly discharged outside the factory premises. A large number of settling ponds, known as "filtration fields", are located near alcohol and sugar factories and meat processing plants, where organic pollutants have been rotting for decades. This leads to the contamination of groundwater, soil and atmospheric air.

At many enterprises, wastewater containing soluble and poorly soluble organic compounds is discharged into the municipal sewage system, from which it flows to municipal treatment facilities. The latter often have imperfect technologies and mostly operate unsatisfactorily. Therefore, insufficiently treated wastewater can enter natural water bodies and cause great harm to both natural ecosystems and people themselves.

In order to provide food enterprises with high-quality water, it must be further purified at the enterprises themselves and used sparingly. This involves the use of economical technologies for washing raw materials, equipment and containers, and the organisation of closed water circulation cycles, in which water can be reused for technological processes after purification and cooling.

Table 4.1. Composition of wastewater from the food industry, mg/dm^3

Factories	Dry residue	Residue after calcination	Total nitrogen	P_2O_5	K_2O	CaO	Na_2O	Cl
Breweries and malt houses	660	240	21	12	40	4	3	
Sugar	1568	423	17	19	46	412	30	
Alcoholic: industrial type	15,000	7700	110	18	5,700	970	320	
settlement type	1440	820	50	8	155	50	17	19
Yeast	2500	1200	10	4	170	120	90	50
Starch	3520	1910	265	93	486	76	16	39
Slaughterhouses (meat processing plants)	3600	1700	150	20	30	–	–	100
Dairy	763	320	36	18	23	40	45	24
Oil and fat	–	–	7	9	10		–	–
Fruit and berries	450	190	4	3	25	–	–	–

Large enterprises that generate large amounts of wastewater should organise local treatment, primarily using biochemical (microbiological) methods. Wastewater pollutants are mostly organic substances that can be transformed into protein, vitamin and other products with the help of microorganisms in biotechnological processes and used in other industries, such as agriculture.

Of all food industries, the alcohol, sugar and meat sub-sectors are the biggest polluters of the environment.

4.1. Pollutants in alcohol production

Alcohol factories are mainly located in small settlements where there is no sewage network or treatment facilities. Waste gases and wastewater are mostly discharged without treatment (Fig. 4.1).

Carbon dioxide and volatile compounds formed during the distillation and rectification of alcohol and the production of feed yeast are released into the atmosphere. At the same time, protein substances and microorganisms are emitted. Wastewater from all production facilities is combined into a common stream and discharged into filtration fields, which are imperfect structures, resulting in contamination of groundwater and soil. Insufficiently treated water also enters surface water bodies, polluting them. Therefore, in order to prevent environmental pollution, it is necessary to build modern, highly efficient treatment facilities that would ensure sufficient wastewater treatment.



Fig. 4.1. Nemyriv alcohol plant [11]

During the preparation of pure yeast cultures, carbon dioxide, some aldehydes, alcohols and other volatile compounds are released into the atmosphere of the workshop and the air. Carbon dioxide and volatile compounds formed during fermentation are also released into the atmosphere.

The technologies developed for producing dry ice from carbon dioxide are used sporadically. Liquefied carbon dioxide is produced more often. During the distillation of mash, toxic volatile compounds are formed (aldehydes, ketones, esters, diacetyl, fusel oils, butyl, isoamyl and other alcohols, etc.). The waste product of production is molasses from molasses-alcohol and grain-potato production. Grain-potato distiller's grains can be used as animal feed. However, in summer, when there is plenty of green fodder, it is rarely used due to transportation difficulties, especially over long distances. A technology has been developed for obtaining enzyme preparations and vitamin B_{12} from distiller's grains,which are used as a feed additive and can also be used to produce feed yeast. Betaine, glutamic acid and glycerine can be extracted from distiller's grains. However, these technologies have not yet found widespread use.

More complex problems arise in the process of disposing of molasses-alcohol distiller's grains, which contains melanoids and caramels that are poorly absorbed by the stomach of animals, and up to 5 % mineral salts. This makes it impossible to use this distiller's grains directly as animal feed. Caramel and melanoids are almost completely resistant to decomposition by microorganisms, which hinders the microbiological treatment of wastewater contaminated with such distiller's grains.

During the transformation of distiller's grains into feed yeast, many volatile compounds are formed, which are released into the atmosphere and pollute the air. These are various fermentation products – carbon dioxide, alcohols, aldehydes, fatty acids, esters, amino acid decomposition products, microorganisms and their decomposition products. Therefore, there is a big problem with the effective treatment of these emissions.

After the production of feed yeast, «secondary stillage» remains, which

consists of caramels, melanoids, mineral salts and yeast metabolism products. Often, this waste is dumped on filtration fields. However, it can be used to grow microorganisms by subjecting it to methane fermentation. With this technology, the liquid is evaporated after methane fermentation. The condensates are used for making mash and other purposes. The residue after drying is used as a vitamin B_{12} concentrate for making animal feed. The use of these technologies would make it possible to eliminate alcohol production waste. However, their use is still limited at present. A technology for the production of granulated organo-mineral fertiliser (OMF) has been developed, but it is also rarely used. Therefore, most of the alcohol and molasses stillage is currently dumped on filtration fields, where harmful substances are formed during biochemical reactions, polluting the environment.

4.2. Pollutants in malt and beer production

In the malt production process, most of the water is used for soaking and washing the grain. Soaking water contains extractive substances and calcium compounds and, together with washing water, has a total pollution level of up to 2000 mgO_2/l according to COD. This water is discharged into the sewage system without treatment. Total water consumption ranges from 3 to 10 m^3 per 1 tonne of barley.

During grain germination, carbon dioxide and volatile compounds are formed, which are released into the atmosphere. During the malt drying process in dryers, a large amount of volatile compounds are released, which enter the atmosphere together with the drying gas. As a result of the Maillard reaction between amino acids and sugars, aldehydes (furfural, oxymethylfurfural, isovaleric aldehyde) are formed, which are also released mainly into the atmosphere along with combustion products. Sometimes, at some enterprises, waste gases are purified in dry or wet filters.

After the preparation of the wort, spent grain (spent grain) remains as waste. It consists of proteins, starch, fats and fibre. Spent grain is mainly used as animal feed. A technology has been developed for growing microorganisms for the production of feed yeast or enzymes.

After boiling the mash with hops, a hop spent grain sediment is formed, which has high feed quality but is not used for animal feed due to its bitter taste. Sometimes it is offered to be burned in a boiler room. A similar problem arises with the disposal of protein sediment formed after the processing of hop wort. The process of preparing seed yeast for fermenting wort raises the same problems as in the production of alcohol.

During the fermentation of beer, carbon dioxide, small amounts of ethyl alcohol and other volatile compounds, and excess yeast are formed. At most plants, carbon dioxide is released into the atmosphere. However, it could be used to make "dry ice". Excess yeast is not yet used due to the bitter taste of hops. The problem of regenerating contaminated kieselguhr, which remains after beer filtration, has not been solved (Fig. 4.2).



Fig. 4.2. PJSC «Obolon» [12]

The vast majority of wastewater in brewing is generated during the process of soaking and rinsing grain and yeast, washing equipment (fermentation tanks, brewing kettles, filters, etc.) and bottles. This water is highly contaminated and decomposes within 2 – 6 hours. It contains:

- suspended solids – 30 – 850 mg/dm^3;
- dry residue – 250 – 2300 mg/dm^3;
- oxidizability – 150 – 960 mgO_2 /dm^3;
- BOC_5 – 300 – 1800 mgO_2 /dm^3;
- total nitrogen – 150 – 270 mg/dm^3;
- phosphorus – 30 – 150 mg P_2 O_5 /dm^3;
- calcium – 90 – 134 mg CaO/dm^3;
- potassium – 40 – 64 mg K_2O/dm^3.
- pH – 6.0 – 7.2.

According to COD, the pollution of these waters can reach 2000 mgO_2/l, while wastewater with a COD of 200 – 300 mgO_2/l is allowed to be discharged into the sewerage system. Therefore, brewing wastewater requires preliminary treatment.

During the decomposition of wastewater, microorganisms produce lactic, butyric and acetic acids, which cause corrosion of the sewerage network and slow down the biological treatment of wastewater. Therefore, brewing wastewater must be discharged into the sewerage system in a "fresh" state, before it becomes acidic. Sometimes it needs to be alkalised.

4.3. Pollutants in yeast production

The main raw material for yeast production is molasses, which, after purification and dilution with water, becomes a medium for yeast cultivation. The production of 1 tonne of pressed yeast requires 100 – 110 m³ of water, and this

amount depends on the technology used (Fig. 4.3). Wastewater consists of mash, which is formed after yeast separation, and effluents from washing yeast milk, filter presses or vacuum filters, equipment and apparatus. Heat exchange water is also produced during the technological process. Heat exchange water is clean, it is not mixed with contaminated effluents, but is cooled and returned to production.

Wastewater is acidic and contains unused molasses compounds, residues of nitrogenous and phosphorous compounds, yeast metabolism products, a significant amount of colloidal impurities and sulfur compounds (cysteine, methionine), which during decomposition form hydrogen sulfide and its derivatives – mercaptans, which are strong poisons and have an unpleasant odour. These effluents are contaminated mainly with organic compounds, whose COD can be 500 mgO_2/l and above. In addition to the above-mentioned impurities, they contain melanoids, caramels and other coloured substances that are difficult to decompose during treatment.



Fig. 4.3. Baking yeast [13]

In order to treat wastewater from yeast factories, it is advisable to use anaerobic-aerobic technology, i.e. preliminary methane fermentation followed by aerobic post-treatment. During methane fermentation, biogas with a content of up to 65 % CH_4 is formed, which can be used as a heat carrier for the needs of treatment facilities and main production.

4.4. Pollutants in bread production

Gas emissions generated during bread baking are products of melain formation and contain aldehydes (isovaleric and fruit). They are emitted into the atmosphere without purification.

The main polluter of the environment is wastewater generated during the washing of equipment and discharged into the municipal sewage system. It consists mainly of organic substances, which are residues of raw materials (flour) and products of their transformation. The COD of wastewater is 500 – 800, and sometimes even 1500 – 2000 mgO_2/dm^3, which significantly exceeds the regulatory requirements (200 – 300 mgO_2/dm^3). Such water requires local

treatment, for example, aerobic fermentation in aerotanks.

If confectionery products are manufactured at bread factories, the amount of pollutants and their content in wastewater increases significantly (Fig. 4.4).

In addition to flour residues, they contain fats, sugar, various flavourings and other ingredients that significantly complicate the wastewater treatment process.



Fig. 4.4. Bakery products [14]

4.5. Pollutants in wine and juice production

The wastewater from the winery consists of effluents from juice storage facilities, the fermentation workshop, the wine ageing and blending workshop, as well as effluents from bottling, container washing and sanitary facilities. These waters are characterised by significant organic pollution. It contains between 80 and 410 mg/dm³ of suspended solids, and its BOC_5 varies between 330 and 760 mg O_2/dm³.

Wastewater is characterised by its variable composition, neutral or slightly acidic reaction, low nitrogen content (2.8 – 24.5 mg/dm^3), phosphorus (0.2 – 6.3 mg/dm^3), potassium (1.3 – 31.8 mg/dm^3), and rapid decay.

The wine-making process produces waste products – racks (combs), which are separated before pressing, pomace after pressing grapes, yeast sediment after fermentation, glue-like sediment after wine clarification, sediment after wine fortification, and cognac pomace after distillation of wine into cognac spirit (Fig. 4.5).

There are technologies for processing secondary raw materials from winemaking. For example, raw alcohol is obtained from pomace and combs. At the same time, distiller's grains remain as secondary waste, which requires disposal. Oil is obtained from the seeds, which is used for soap production. At the same time, pomace remains, which can be used as fertiliser. Some factories

produce pectin from pomace. Pomace and grape skins can be used as animal feed. Yeast sediments contain proteins, pectin and many other substances that complicate their disposal. Due to their significant ethyl alcohol content, they cannot be used directly as animal feed.



Fig. 4.5. Wine production plant [15]

At many wine-making plants, all these wastes are subject to secondary processing to produce low-quality wines. Tartaric acid can be obtained from yeast sediments by distillation. After processing the waste, a slurry remains, which contains fatty acids, lactic acid, pectin and nitrogen compounds. The insoluble residue is separated by filtration and used as animal feed, and the filtrate is discharged into the sewer system.

4.6. Pollutants in sugar production

The amount of water consumed and the requirements for its composition depend on the equipment installed at the plant and the technological process adopted. The average consumption of fresh water is about 60 m^3 per 1 tonne of sugar produced. Water is used for washing and transporting beets, washing filters and other equipment, and for extracting (diffusing) sugar. (Fig. 4.6).

Sugar factories face significant difficulties with wastewater treatment. The most polluted are diffusion and pulp press waters, which can account for 140 and 40 % of the weight of processed beets, respectively. They contain a significant amount of organic matter in dissolved form and in the form of suspended particles. The pollution consists of sucrose and its decomposition products, proteins and other nitrogenous substances, pectin, saponin, pentoses, potassium, magnesium, phosphoric and hydrochloric acid salts. These waters are a good breeding ground for microorganisms and are easily subject to fermentation and decay processes.



Fig. 4.6. Sugar production plant [16]

Some of the water is reused, for example, condensate from syrup evaporation. However, it is contaminated with ammonia and other substances, so it must be purified. The amount of condensate depends on the heat utilisation scheme adopted at the factory and is about 140 % of the beet mass. Water used to cool turbines and grate bars, boilers, mixers and other equipment, which is classified as conditionally clean, can be reused.

Contaminated water of category III has a COD of up to 5,000 mgO_2/dm^3. It contains suspended solids formed on filters after defecation, saturation, sulphitation, soil residues and organic substances in solid (beet tails, tops) and dissolved states (carbohydrates, protein substances, saponin, etc.), which come with conveyor washing water. After combining with wastewater from the pulp areas and after washing the equipment, they enter the settling tank and then the storage ponds. The latter are ineffective treatment facilities because organic substances rot in them.

The products of decay pollute water bodies and soil as a result of water infiltration and atmospheric air. Proteins, amino acids and amino acid derivatives – betaines, choline and other organic compounds – can be transformed into harmful toxic compounds. For example, choline forms toxic trimethylamine. During the decomposition of amino acids, amines and ammonia are formed. The products of the decomposition of pectin contained in pomace press water are galactose and other sugars, which after fermentation are transformed into lactic acid. The latter undergoes further transformation into metabolic products with the help of microorganisms. These processes, which take place in the storage pond, absorb a significant amount of oxygen dissolved in water.

Significant environmental pollutants are sediments that form in storage tanks and remain on filters after defecation and saturation of diffusion juice. They consist of organic and mineral substances. After filtration, the sediments consist mainly of lime, which is used in the technological process. Some of these

sediments are used to lime acidic soils. Work is also underway to develop technology for their use for other purposes. In particular, calcium-containing sediments can be reused after regeneration.

There are certain problems with the disposal of pomace and pomace water. Pomace is mainly used for animal feed. However, there are problems with its timely removal. During long-term storage, it rots and pollutes the environment. Pomace press water is discharged into the general drain (category III wastewater), but it can be used in the production of feed yeast and other products.

4.7. Pollutants in fruit and vegetable production

Wastewater from fruit and vegetable production is contaminated with particles and juices from fruits and vegetables, their decomposition products, and soil residues. In most cases, it is combined with domestic sewage after preliminary settling and discharged into storage ponds or the sewerage system. Wastewater is generated after washing vegetables and fruits, equipment, containers, and blanching and pasteurisation. The COD of such water can be 1500 – 3000 mgO_2/dm^3, and in some cases even higher.

In the juice production process, wastewater from the pressing department is more contaminated with juice and fruit particles, which mainly enter during the washing of equipment and premises. Thus, the entry of apple juice into wastewater can increase the BOC_5 to 50 thousand mgO_2/dm^3. General wastewater has low pH values (5.2 on average) and a high content of suspended solids. During the processing of 1 kg of apples, almost 4 litres of wastewater is produced (Fig. 4.7).



Fig. 4.7. Juice production [17]

During juice production, pomace is formed, which is mainly used as animal feed. A characteristic feature is that it cannot be stored for long and rots, causing air, water and soil pollution. A technology for producing pectin from apple pomace has been proposed, but it is not always used.

The treatment of wastewater generated during the juice concentration

process is a significant problem.

Particularly significant complications arise in the case of wastewater treatment from a barometric condenser, which is highly polluted and produced in large quantities. Reuse of water requires thorough disinfection.

4.8. Pollutants in oil and fat production

Oil and fat production enterprises use water for cooling, technological and sanitary needs. At enterprises that do not use heat exchange water recirculation, water consumption is up to 190 m^3 per 1 tonne of oil. When recirculation is used, water consumption is reduced to 20 m^3 per 1 tonne of oil (Fig. 4.8).

Depending on the nature of the contamination, wastewater is divided into conditionally clean water, which is used in heat exchange equipment, and process water. Conditionally clean water should not be mixed with process water and can be reused after cooling.

If it is not reused, it is discharged through a separate sewerage network and mixed with treated process wastewater after grease removal. Stormwater from the enterprise's territory also enters here.

Process water is contaminated with organic substances (fats, organic acids, aldehydes, ketones, etc.), which are present both in dissolved form and in the form of suspended substances and emulsions.



Fig. 4.8. Oil production [18]

The effluents contain up to 50 mg/dm^3 and more fat-like substances, more than 500 mg/dm^3 suspended particles, and have a BOC of more than 500 mgO_2/dm^3. Electroflotation, pressure flotation and other methods are used to remove fat from this wastewater. Many factories use grease traps, which do not completely remove the grease. The biological treatment envisaged in the project is largely not used. No effective technology has yet been developed for treating wastewater from soap and surfactants formed during the refining stage.

Before storage, the raw materials are blown with air in separators and winnowers, which helps to remove a large amount of dust (5 – 8 g/m³). The dust is mainly cleaned in cyclones, where the degree of cleaning does not exceed 85 %. Therefore, a large amount of dust enters the atmosphere.

During storage, the seeds are ventilated and dried with heated air. Ventilation emissions containing volatile products of raw material metabolism and carbon dioxide formed during seed respiration are released into the atmosphere without purification.

During the extraction of oil from the residues after pressing the crushed seeds, volatile substances (petrol, alcohols, ketones, hydrocarbons, etc.) are removed. During the process of distilling solvents from the micelle and refining the oil, soap and other products are formed, which are separated in a settling tank. At all stages of the process, the solvent enters the atmosphere. The same is observed in the process of drying meal (raw material residues after pressing and oil extraction). This leads to contamination of factory premises and the environment.

4.9. Pollutants in the production of dairy products

Wastewater from dairy plants is a powerful source of environmental pollution and is divided into four types: production, heat exchange, domestic and storm water. Production wastewater contains a large amount of pollutants resulting from various technological operations, as well as from washing containers and cleaning production premises (Fig. 4.9).



Fig. 4.9. Dairy production [19]

Depending on the capacity of the enterprise, the amount of wastewater varies within a few hundred cubic metres per day. The consumption and composition of wastewater from the dairy industry are also determined by the profile of the

enterprise and the water supply system (Table 4.2).

Table 4.2. Composition of total effluent from dairy industry enterprises

Enterprises	Suspended solids, mg/dm^3	COD, mg O_2/dm^3	BSK, mg O_2/dm^3	Fats, mg/dm^3	Chlorides, mg/dm^3	Total nitrogen, mg/dm^3	Phosphorus, mg/dm^3	pH
Municipal dairy plants	350	1400	1200	Up to 100	150	60	8	6.5 – 8.5
Dry and condensed milk factories	350	1200	10	Up to 100	150	50	7	6.8 – 7.4
Cheese factories	600	3,000	2,400	Up to 100	200	90	16	6.2 – 7

Wastewater that exceeds regulatory standards for pollution is discharged into the municipal sewerage system or into settling ponds located outside the city limits. This leads to pollution of water, air and soil. Therefore, local treatment facilities should be organised. In the case of relatively low pollution (COD up to 1000 mgO_2/dm^3, aerobic biological treatment can be used. To treat wastewater from cheese factories, where the COD can be as high as 3000 mgO_2/dm^3, anaerobic-aerobic treatment is recommended.

A particular source of wastewater pollution is whey, a by-product of milk processing, which is used to make various products (concentrated and dry whey, milk sugar, cheese mass, casein, various beverages, etc.), in baking bread and as animal feed. It is used to prepare bacterial starter cultures for silage. Whey cannot be stored for long due to its rapid decay, so it is discharged into the sewer system. The COD of whey is 70,000 – 80,000 mgO_2/dm^3, while the COD of total effluent does not exceed 3,000 mgO_2/dm^3 (see Table 4.2).

Heat and power engineering, motor transport, and organised technological emissions are pollutants of the atmospheric air. However, the volume of these emissions is insignificant. The amount of emissions and their composition depend on the profile of the plant and the range of products it manufactures. For example, in the production of casein, a lot of dust is generated during grinding and in dryers. Emissions into the atmosphere can contain up to 500 mg/m^3 of casein dust.

During the production of dry milk, a large amount of milk dust enters the atmosphere from dryers. The gas-smoke stream is cleaned using cyclones, bag filters and wet filters, the design of which is outdated and, for the most part, physically worn out.

4.10. Pollutants in meat production

The main air pollutants in meat production are technical and feed product workshops, fat processing departments, sausage workshops and water treatment facilities. In technical product workshops, the air is polluted by emissions from transportation, grinding, heat treatment of raw materials, production of meat and

bone meal, blood drying and fat dehydration.

Many harmful gases are emitted in the pre-slaughter animal holding area. The source of their formation is manure and feed waste. Gas emissions are formed in the primary processing workshop for slaughtered animals (wool by-products department) as a result of burning ears, heads and carcasses, as well as in workshops for storing and processing hides, producing dry blood, etc. A particularly large amount of pollution is contained in the rumen (the contents of the stomach of animals, which is separated after slaughter) (Fig. 4.10).

Gas emissions from meat processing plants are determined by the capacity of the enterprise and the production profile in terms of quantity and composition. They contain acids (acetic, propionic, butyric, isobutyric, valeric), aldehydes (acetaldehyde, butyric aldehyde, caproic, furan – furfural, acrolein), ketones (methylethylketone, methylbutylketone, diacetyl), alcohols and phenols (ethanol, butanol, cresol, propanol, butanol isomers, phenol, pyrocatechin), ethers (pyrogallol and guaiacol derivatives, etc.), sulphur derivatives (sulphides and disulphides) and hydrogen sulphide (mercaptans), amines (methyl-, dimethyl- and trimethylamines, diethylamine, triethylamine, dibutylamine), hydrocarbons (methane, ethane, propane, butane) and inorganic compounds (sulphur and nitrogen oxides, hydrogen sulphide, ammonia, etc.).



Fig. 4.10. Meat product manufacturing [20]

Smoke from smoking contains resinous compounds. Gas and smoke emissions are cleaned of dust in cyclones, bag filters or scrubbers. Toxic compounds are neutralised by thermal and catalytic combustion. Outdated equipment makes it impossible to effectively clean emissions and unorganised emissions, which causes environmental pollution.

Wastewater and production waste, which are generated in almost all technological operations, cause particular damage to the environment. The amount of wastewater depends on the capacity of the enterprise, its production profile, technical equipment and the size of the factory territory. Each tonne of live animal weight generates 6.9 – 8.9 m³ of wastewater. A significant amount of

fat is discharged from the slaughterhouse along with the wastewater. Each slaughtered head of cattle generates 1.2 – 1.8 kg of fat, and each pig generates 0.4 – 0.6 kg of fat.

Waste also includes blood, whose BOC is about 100,000 mgO_2/dm^3. Along with waste that is used as secondary raw material, slaughterhouses produce a significant amount of solid waste, stomach contents and others. This waste is collected separately, transported to fields and composted. This results in secondary pollution of the environment. Wastewater pollution depends on the degree of waste utilisation. Particularly polluted wastewater is generated at small slaughterhouses, where waste processing is unprofitable. At such enterprises, wastewater is often discharged into storage ponds without treatment, causing great damage to the environment.

The characteristics of wastewater from meat enterprises are presented in Table 4.3.

Table 4.3. Characteristics of wastewater from meat processing plants

Indicator	Slaughterhouse, fat rendering plant	Slaughterhouse, smokehouse, fat rendering plant, cold store	Slaughterhouse, smokehouse, canning factory, fat rendering plant	Smokehouse	Slaughterhouse, bacon factory
Productivity of meat processing enterprises, tonnes per day	123.1	112.7	47.7	19.2	76.2
Amount of wastewater per 1 tonne of meat, m^3	4.7	6.6	7.2	4.7	120
Dry residue, mg/dm^3	4731	3824	3969	12382	5136
Total suspended solids, mg/dm^3	2901	1415	1029	1293	1452
Chlorides, mg Cl/dm^3	518	263	974	5684	188
Nitrogen (organic), mg/dm^3	301	169	507	279	513
Nitrogen (protein), mg/dm^3	111	27	97	100	160
Fats, mg/dm^3	400	201	335	289	489
pH	6.6	7.21	7.65	6.52	7.08

The COD of the total flow is 2 – 3 thousand mgO_2/dm^3. The high fat content necessitates its preliminary capture in grease traps, which are mostly ineffective.

After preliminary treatment, wastewater is discharged into the municipal sewerage system and, together with domestic sewage, is transported to municipal treatment facilities. If there are no appropriate municipal facilities, wastewater

from meat processing plants is treated in factory treatment facilities.

An effective treatment technology involves methane fermentation in the first stage and aerobic fermentation in the second stage of treatment. This treatment produces methane and microbial biomass enriched with vitamin $B_{12}$and other B vitamins. The biomass can be used as animal feed. However, treatment facilities are not yet being built at domestic meat processing plants, and wastewater is discharged into a settling tank, where it rots and pollutes the air, soil and groundwater.

Meat processing generates a large amount of solid waste: horns, hooves, skin remnants, wool, etc., which are disposed of in landfills, where they slowly decompose during the rotting process (Fig. 4.11). There are technologies for processing this waste into animal feed containing amino acids.



Fig. 4.11. Meat production waste [21]

4.11. Pollutants in fish product manufacturing

The main environmental pollutants from fish processing plants are wastewater. The largest amount of wastewater is generated during fish gutting (almost 2 m³ per 1 tonne of fish) and in the salting shop (almost 0.4 m³ per 1 tonne of fish) (Fig. 4.12).



Fig. 4.12. Fish gutting line [22]

At fish meal and fish oil production plants, 1 – 4 m³ of wastewater is generated per 1 tonne of raw materials, excluding heat exchange water. If this

water is taken into account, the total amount of wastewater discharged into the sewer system is 30 – 50 m³ per 1 tonne of raw materials.

The characteristics of wastewater generated at different stages of production are shown in Table 4.4.

Wastewater from various workshops is characterised by a high content of suspended solids, fat, chlorides, phosphorus and nitrogen (Table 4.4). It contains proteins, amino acids, fats and other substances. All wastewater is discharged into the sewerage system. Spent brine is also periodically discharged into the sewerage system. These effluents, together with domestic effluents, are subject to biological treatment at municipal treatment plants. It has been proposed to obtain feed and technical products and fertilisers from wastewater. However, even in this case, a lot of contaminated wastewater remains.

Table 4.4. Characteristics of wastewater from fish factories

Composition and indicators of wastewater	Wastewater from workshops			Total effluent
	smoking	canning	fat	
Suspended solids, mg/dk³	1350	1700	2800	1430
Including volatile substances	860	1450	2320	1200
Dry residue, mg/dm³	790	2470	6940	4450
Including volatile compounds	1220	1580	4310	2250
Chlorides, mg/dm³	3540	744	1250	1400
Sulphates, mg/dm³	10	16	24	19
COD, mg O_2 /dm³	1800	2000	3290	2940
BSK, mg O_2 /dm³	1295	1300	2220	2000
Fats, mg/dm³	375	810	1940	1800
Phenols, mg/dm³	0.04	0.12	0.74	0.16
Phosphorus, mg/dm³	28.7	8.93	72.64	14.13
Nitrogen (total), mg/dm³	47	34	224	121
Nitrogen (ammonium), mg/dm³	10	31	31	61
pH	7.7	7	8	7

The approximate composition and amount of pollutants in general wastewater from individual workshops and enterprises are given in Table 4.5.

Trimethylamine has a particularly unpleasant odour. Therefore, gas emissions are subject to deodorisation, incineration or chemical purification. A by-product is trunk fat, during the refining and hydrogenation of which soap and soap-like products are formed, which are not yet utilised.

Pollution generated in fish smoking workshops is particularly harmful. Emissions from these workshops contain substances with an unpleasant odour. Gas emissions from fish factories, which are produced in all processes related to the drying of products (fish, fish meal, etc.), contain up to 50 components (amines, sulphides, mercaptans, trimethylamine, etc.).

These data were obtained during the study of general wastewater from fish processing enterprises.

Suspended solids include fish fats, vegetable oils, proteins, and minerals. The content of suspended solids varies widely and depends significantly on the amount of raw materials used and the depth of their processing, averaging 100–2000 mg/dm^3. A particularly large amount of suspended solids enters the wastewater during the machine forming of meatballs and patties, during the washing of roasting ovens, blanching of fish, during the pressing of boiled fish mass during the production of feed meal, etc. It can reach 20 – 50 g/dm^3.

Table 4.5. Composition of wastewater from fish processing enterprises

Pollutant indicators	Amount of pollutants, mg/dm3								
	1	2	3	4	5	6	7	8	9
Suspended substances	640 – 2500	170 – 2630	189 – 7630	480 – 2500	1350	400 – 5730	500	2800	330 – 650
BSK_5	160 – 1675	80 – 425	1169	338	950	420 – 2300	700	1780	–
BSK_{full}	820 – 1570	512 – 2860	1300	660	1295	510 – 2750	820	2200	370 – 1650
HSC	1130 – 2160	600 – 3400	200	1060	1800	620 – 3500	1180	3295	560 – 1800
Total nitrogen	37 – 45	24 – 120	49 – 75	96 – 210	23 – 91	6 – 240	38	224	32 – 54
Ammonium nitrogen	10 – 12	8.0 – 14	3.4 – 5.1	10	12	15	3.5	31	–
Ether-soluble substances	98 – 880	80 – 320	190 – 810	120 – 218	375	62 – 500	120 – 650	1940	27 – 14430
Dense residue	2400 – 2700	6500 – 16500	5960 – 46030	4450 – 1600	7900	13,900 – 26000	2100	6940	1800
Chlorides	600 – 1100	1000 – 5000	800 – 1050	1050 – 2720	3540	1160 – 4150	300 – 600	350	300 – 800
Phenols	0.15	0.17	0.12	traces	0.24	traces	traces	traces	–
Temperature, ^{0} C	17 – 20	14 – 16	17 – 18	16	18	14 – 16	18 – 20	37	12
pH	6.8 – 7.0	6.4 – 7.5	6.8 – 7.5	7.3	7.0 – 7.7	6.5 – 7.0	6.5 – 7.0	7.0	7.0

Notes: 1 – fish canning factory; 2 – factory for the production of salted, dried and smoked fish products; 3 – canning workshop; 4 – salting workshop; 5 – smoking and drying workshop; 6 – pre-preservation workshop; 7 – culinary workshop; 8 – fat and flour workshop; 9 – refrigerator.

Most organic impurities in wastewater are easily oxidised: unsaturated fatty acids, vitamins, dissolved protein, amino acids. Some are more resistant to oxidation: saturated fatty acids, insoluble protein, non-protein nitrogenous substances, fibre, etc. Nevertheless, organic substances can be characterised as easily biochemically oxidised, and their BOC_{full} averages 1500 – 2000 mgO_2/dm^3. Chemical oxygen demand (COD) averages 2000 – 3000 mgO_2/dm^3, since the pollution is mainly organic.

In the effluents of fish processing enterprises, total nitrogen is mainly

represented by fish proteins in the form of the smallest pieces, in a suspended state, in a colloidal and dissolved form, as well as in the form of non-protein compounds (primarily amine nitrogen). The amount of total nitrogen in wastewater ranges from tens to hundreds of mg/dm^3. Due to the specific composition of raw materials and auxiliary materials, wastewater is very rich in biogenic elements (carbon, oxygen, nitrogen, hydrogen, phosphorus).

A characteristic feature of wastewater is its high content of fats (or ether-soluble substances), which are in an emulsified state and form a film on the surface of the wastewater. The fats in wastewater from the raw materials department are tiny balls surrounded by a hydrated protein shell, which float very slowly during settling. Fats that get into the brine from fish during salting settle a bit better. Fats from fat and flour production and vegetable oils from frying ovens float easily because the proteins in these wastewater are coagulated and the wastewater itself has a temperature of 30 – 60 ^{0}C. The concentration of fats in wastewater varies widely, from traces to 5000 mg/dm^3 and more.

The total content of dense residue in wastewater is significant, averaging about 5000 mg/dm^3. At the same time, the content of organic and mineral substances in a dissolved state is 40 and 60 %, respectively. The effluent contains a large amount of chloride salts – from 100 to 1400 mg/dm^3, which in terms of ionic composition brings them closer to brine. The significant content of mineral substances in the dense residue is caused primarily by the presence of chlorides. Wastewater from smoking production facilities may contain 50 mg/dm^3 or more of phenols.

The concentration of impurities in general wastewater can be significantly reduced by organising the separation of valuable substances (protein, fish fat, vegetable oil) in a series of processes where concentrated effluents are formed: pre-press broths, wastewater from fish blanching, wastewater from automatic meatball production, and wastewater from cleaning roasting ovens.

Wastewater is divided into three groups according to its aggressiveness:

- weakly aggressive (pH 6.0 – 6.6, pH 8 – 9);
- highly aggressive (pH < 6, pH >9);
- non-aggressive (pH 6.5 – 8.0).

Wastewater from fish processing plants is mostly non-aggressive. The pH value is 6.5 – 7.5 (average 7.0), but can drop to 6.0 – 6.4 due to rapid acidification of the liquid. The pH of the wastewater increases when the equipment is washed with alkaline cleaning agents. The average monthly temperature of wastewater ranges from 20 ^{0}C (in summer) to 13 ^{0}C (in winter).

Depending on the dispersibility of impurities, wastewater is divided into four groups:

- insoluble in water, coarse-dispersed impurities of organic and inorganic origin. This group includes pieces of fish, vegetables, cereal crumbs, flour, as well as fats and oils that have undergone heat treatment. These impurities form unstable systems with water, as they can precipitate or float to the surface of the water. A significant portion of these impurities

can be removed from water by filtration, precipitation, centrifugation, and flotation;

- additives with a colloidal degree of dispersion with particle sizes $(0.1 \div 0.001) \times 10^{-6}$m. The boundary between suspensions and colloidal solutions can be characterised by the appearance of Brownian motion of particles, in which these particles cannot settle under the action of gravity or float to the surface of the liquid. Hydrophilic and hydrophobic impurities in this group (proteins, lipoprotein complexes) form systems with water that have special molecular-kinetic properties. When external physical and chemical conditions (pH of the environment, temperature) change, impurities are able to change their aggregate state, collide, agglomerate and precipitate or float to the surface of the water;
- impurities with particle sizes less than 10^{-9} m. They have a dispersibility close to that of molecules (proteins, microorganisms) and form solutions in water. Physical-chemical and biological methods are used to purify wastewater from these impurities;
- impurities with particle sizes less than 10^{-10}m, which corresponds to the ionic degree of dispersion. These are solutions of acids, bases, and salts. To reduce their concentration in wastewater, ion exchange, electrodialysis, membrane technology, and biological treatment are used.

Since the wastewater from fish processing enterprises, which is generated in separate technological processes, varies significantly in composition, quantity and properties of impurities, it can be divided into several groups:

- wastewater from salting, soaking, processing, and rinsing of salted fish, which, along with fish proteins and fats, contains a significant amount of table salt and non-protein nitrogenous substances;
- waste brine from fish salting lines;
- wastewater from cooling and washing roasting ovens, in which proteins are coagulated and fats are deprived of hydrated shells and additionally contain vegetable oil;
- Wastewater from fat and flour production, from blanching fish, where proteins are also coagulated and have a temperature of 40 – 50°^{0}C;
- wastewater from cooling canned food in an autoclave after sterilisation, which can be classified as conditionally clean in terms of impurity content.

Based on this classification, it is possible to create a sequential, reversible water consumption and utilisation of valuable feed and technical substances from wastewater in certain technological processes. To solve such problems, it is necessary to treat and disinfect wastewater, both before using water in circulation or for the extraction of valuable substances, and before discharging general wastewater into the sewerage system or a reservoir.

4.12. Conditions for the discharge of wastewater from sewerage networks

Most processing enterprises are located in cities with centralised sewerage systems, where industrial wastewater is mixed with domestic wastewater from the

city and then treated at municipal biological treatment plants. Some (smaller) enterprises are located on the coast and discharge wastewater into water bodies. For example, fish processing is also carried out on floating bases and fish processing freezer trawlers, and the wastewater is then discharged into water bodies.

Requirements for the content of pollutants in discharged wastewater have been established for each category of enterprise. These requirements must be strictly adhered to by enterprises.

Requirements for wastewater discharged into municipal sewers

These requirements are listed in Table 4.6. Wastewater must not contain harmful impurities in concentrations that prevent its biological treatment.

The discharge of wastewater containing radioactive elements is not permitted. Wastewater must not contain combustible impurities and dissolved gaseous substances capable of forming explosive mixtures in sewer drains, causing destructive effects on pipe materials, or disrupting the operation of networks and structures. Acidic and alkaline effluents must be neutralised. Industrial wastewater that does not meet these requirements must be treated at the factory's treatment facilities.

Table 4.6. Requirements for wastewater

Indicators	Units of measurement	MPC for wastewater
Suspended solids	mg/dm^3	500
Ash content of suspended solids	%	3
Ether-soluble substances	mg/dm^3	20
BOC_{total}	mgO_2/dm^3	50
COD	mgO_2/dm^3	800
pH	–	6.5 – 8.5
Temperature	^{0} C	<40
Colour	–	1/16
Dense residue	mg/dm^3	2000
Chlorides	mg/dm^3	35
Sulphates	mg/dm^3	500

At the treatment facilities of fish processing enterprises, wastewater is cleaned of large inclusions, sand, suspended, ether-soluble and protein substances, and disinfected. Feed waste is disposed of.

Mechanical, chemical, and physicochemical methods are usually used to remove such contaminants. If fish processing enterprises do not have access to the municipal sewage system and discharge wastewater directly into a water BOCy, then a biological treatment plant must be provided in the factory treatment system.

Questions for discussion and self-assessment

1. What are the main environmental problems of the food industry?
2. What are the sources of air pollution in food production?
3. What are the sources of water pollution in the food industry?
4. What waste is generated in food production?
5. What problems arise in the process of producing environmentally safe food products?
6. What are the environmental problems of water supply in the food industry?
7. Name the main environmental problems of wastewater disposal in the food industry.
8. Formulate the main environmental problems in alcohol production.
9. Formulate the main environmental problems in the production of malt and beer.
10. What are the environmental problems associated with yeast production?
11. What are the main environmental problems in bread production?
12. What are the main environmental problems in wine and juice production?
13. What are the main environmental problems in sugar production?
14. What are the main environmental problems in the production of canned fruits and vegetables?
15. What are the main environmental problems in oil and fat production?
16. What are the environmental problems in dairy production?
17. What are the environmental problems in meat production?
18. Name the sources of food contamination.
19. What are the environmental management issues in the food industry?

CHAPTER 5. REQUIREMENTS FOR WATER, WATER SUPPLY AND WATER DISPOSAL IN FOOD ENTERPRISES

5.1. Use of water in the food industry

Water is a component of all organisms in the biosphere (50 – 90 % or more). It acts as a structural component, solvent and carrier of nutrients, participant in biochemical processes, and regulator of heat exchange with the environment. Water regulates the planet's climate and supports human economic and industrial activities.

People's lives and health depend on the availability of water. Every day, a person consumes about 2 litres of water. Water is needed for preparing food and beverages and for sanitary and hygienic needs (bathing, cleaning rooms, washing dishes, etc.). According to the Law of Ukraine «On Drinking Water», providing the population with high-quality drinking water in sufficient quantities is one of the main tasks of the state's development. At the same time, the problem of drinking water quality has become a pronounced social issue. Therefore, supplying the population with high-quality water is a leading task, the solution of which is aimed at ensuring a full and safe water supply to all settlements.

In the food industry, water quality is strictly controlled, as the quality of products depends on it. Good-quality drinking water is used not only for basic technological processes, but also in many auxiliary processes as a raw material, reagent, heat carrier, for washing raw materials, equipment, premises and containers. For example, the production of 1 litre of beer consumes 20 – 35 litres of water, 1 kg of sugar – up to 200 litres, 1 litre of dairy products – up to 1 litre, and 1 can of canned vegetables – up to 40 litres of water.

Depending on its purpose in the food industry, water can be classified as follows, in particular for:

- technological needs;
- feeding steam boilers;
- cooling;
- sanitary purposes;
- washing dishes, raw materials, equipment, premises;
- water supply for laboratories and drinking.

The volume of water used in industry is estimated by the water intensity of production, which is understood as the amount of water required to produce one tonne of finished product (m^3/t). The water intensity of different types of products varies widely, m^3/t: beer – 25 – 30, sugar – 200. A 300,000-kW thermal power plant requires about 300 $km^3$of water per year to operate.

Water consumption by the population is characterised by specific water consumption, which is understood to mean the daily volume of water in litres, required to meet all the needs of one inhabitant of a city or village. Specific water consumption in cities is higher than in villages. It largely depends on the level of infrastructure (availability of water supply, sewerage, central water heating, etc.). Thus, specific water consumption for some cities is, l/day: New York – 600, Paris

– 500, Kyiv – 300, London – 263. In large cities with a population of more than 3 million people, daily water consumption is 2 million m^3 and annual consumption is about[1] billion m^3. At the same time, the water must be of high quality, which requires quite complex water treatment technology.

5.2. Water quality requirements

Water quality depends on its purpose, the type of products manufactured and the technology used at the enterprise.

Water for technological needs (process water) is water used for manufacturing products, processing raw materials, washing, transportation, as well as water used for final product processing. In the food industry, process water must meet the requirements for drinking water and domestic needs, as well as additional requirements due to the specific conditions of the industry.

In the alcohol and spirits industry, water is used to prepare mash, tinctures, liqueurs, dilute alcohol, cook syrup, and produce varietal vodka. The quality of water used to prepare mash must correspond to the quality of drinking and process water used in the yeast industry.

During the production of tinctures, water contains calcium, magnesium and heavy metals that react with pectin, tannins and acids found in fruits and berries. The substances formed then precipitate. Calcium and magnesium carbonates and sulphates, as well as iron salts, can cause cloudiness due to their reduced solubility in alcoholic solutions. Therefore, for the production of fruit drinks, it is desirable to use deeply desalinated (distilled) water, which is prepared, for example, by ion exchange. In the production of varietal vodka, water with a hardness of less than 0.4 mmol/dm^3 is used, as well as desalinated (distilled) water for the production of colourings, candy syrup, honey-sugar syrups and high-quality vodka products that are prone to cloudiness.

During the production of yeast, process water is used to prepare yeast wort and rinse the product. It must meet the requirements for drinking water and not contain nitrates, which inhibit yeast growth at a concentration of 0.02 %. The presence of iron and manganese causes the finished product to darken, which is undesirable in the production of baker's yeast.

In sugar production, water from pulp presses, condensates from evaporators and additional fresh water are fed to the diffusion. Fresh water should have a minimum dry residue, low content of calcium sulphate and magnesium chloride, nitrates, potassium salts and organic compounds. A high dry residue and nitrate content increases molasses yield and increases the ash content of sugar and pulp. Sulphates, chlorides and especially nitrates inhibit sugar crystallisation. Potassium salts increase the colour of juices. The brown colour of juices is also due to the presence of sulphate and chloride ions in the water. Organic compounds are prone to decay and complicate the diffusion process. Secondary process water, which is used repeatedly, must undergo inter-operational treatment to improve its quality.

In brewing, water is the main component of beer, the quality of which is

largely determined by the impurities present. In addition to the usual requirements for drinking water, process water is subject to specific requirements regarding alkalinity, hardness and the presence of nitrates and silicates. The total alkalinity must be low, less than the total hardness. Sodium alkalinity, which indicates the presence of soda (otherwise, the wort becomes alkalised), is unacceptable. Calcium salts in the form of acidic carbonates cause an unfavourable alkalising effect. However, the content of these metals in the form of sulphates and chlorides has a beneficial effect. The presence of magnesium increases the bitterness of beer. High concentrations of nitrates and nitrites inhibit yeast growth and negatively affect the taste of beer. The presence of iron has a negative effect on the fermentation process and the taste of beer. The latter also contributes to the cloudiness of beer.

The water used to produce clear fruit juices and beverages must be of very high quality, at the level of distillate, and the water used to preserve green peas must have a hardness of less than 7 mmol/dm^3. However, when it is necessary to eliminate the possibility of cloudiness caused by the transition of starch from the grains into solution, hard water with a high calcium salt content is used. In this case, the formation of insoluble calcium pectinates on the surface of the grains inhibits the transition of starch into aqueous solution. Insoluble calcium pectates also improve the consistency of some fruits, such as strawberries. Water for other technological purposes must meet the requirements for drinking water.

When processing potatoes, process water must meet drinking water requirements, have the lowest possible temperature, low hardness and low mineral salt concentration. It must not contain iron or manganese salts. Elevated water temperature stimulates the growth of microorganisms. High hardness and high mineral salt content increase the ash content of starch. Iron and manganese compounds contribute to the yellow colouring of starch, as well as the formation of dark spots, which are distinguished by the release of iron by iron-loving bacteria. Magnesium, which passes from water into starch, increases its hygroscopicity.

Other sectors of the food industry, in particular meat, canned meat, fish, dairy, and poultry processing, use large amounts of process water that meets drinking water requirements. In addition, it must have greater bacteriological purity, low hardness and contain no iron at all. Even the slightest amount of iron can cause a change in the smell and taste of products.

Water for drinking and domestic use

Water supplied by centralised water supply systems for drinking and domestic use (drinking water) must comply with the requirements *of DSTU 7525:2014 «Drinking water. Requirements and methods of quality control».*

Drinking water must be epidemiologically safe, harmless in terms of chemical composition and have favourable organoleptic properties (Table 5.1).

Table 5.1. Regulatory indicators of drinking water quality

No.	Indicator	Unit of measurement	Standard			
			DSTU 7525:2014	DSanPiN 2.2.4-171-10	WHO	EU
Organoleptic indicators						
1.	Appearance	–	–	–	–	–
2.	Smell	Points	2	2	Should be pleasant	2 – 3 (0)
3.	Taste and aftertaste	Points	2	2		2 – 3 (0)
4.	Colour	Grad.	20	20 (35)	15	Pt/Co scale 10(1) mg/l
5.	Turbidity	mg/dm^3	1.5	0.5 (1.5)	2	SiO_2
Toxicological indicators						
1.	Aluminium	mg/l	0.5	0.2 (0.5)	0.2	0.2 (0.5)
2.	Barium	mg/l	–	0	0.7	0.1
3.	Beryllium	mg/l	0.0002	–	–	–
4.	Boron	mg/l	–	–	0.3	0.3
5.	Molybdenum	mg/l	0.25	–	0.07	–
6.	Arsenic	mg/l	0.05	0.01	0.01	0.01
7.	Nickel	mg/l	–	0.1	0.02	0.02
8.	Mercury	mg/l	–	–	0.001	0.01
9.	Lead	mg/l	0.03	0.01	0.01	0.01
10.	Selenium	mg/l	0.001	0.01	0.01	0.01
11.	Strontium	mg/l	7	–	–	–
12.	Fluorine and fluorides	mg/l	0.7 – 1.5	0.7 – 1.5	1.5	1.5
13.	Chromium (+6)	mg/l	–	–	0.05	0.05
14.	Cyanides	mg/l	–	–	0.07	0.05
15.	Cadmium	mg/l	–	–	0.003	0.005
16.	Lindane	mg/l	–	Pesticides	0.002	Pesticides
17.	DT	mg/l	–	0.0001	0.002	0.0001
18.	2,4-D	mg/l	–	–	0.03	–
19.	Atrazine	mg/l	–	–	0.002	–
20.	Simazine	mg/l	–	–	0.002	–
21.	Benzene	mg/l	–	–	0.01	–
22.	Benz(a)pyrene	mg/l	–	–	0.0007	–
23.	Phenols	mg/l	–	Chlorophenols 0.0003	–	0.0005 (phenol index)
24.	Chlorinated ethylenes: 1,1-dichloroethylene trichloroethylene tetrachloroethylene	mg/l	 –	 –	 – 0.7 0.4	 –
Indicators affecting the organoleptic properties of water						
1.	Hydrogen index	pH	6.0	6.5 – 8.5	–	6.5 – 9.5
2.	Total hardness	mmol/l	7	1.5 – 7.0 (10.0)	–	–
3.	Petroleum products	mg/l	–	–	–	–
4.	PAR	mg/l	–	–	–	0.2

5.	Total mineralisation	mg/l	100	100 – 1000 (1500)	1500 (–)	
6.	Iron	mg/l	0.3	0.3	0.3	0.2 (0.05)
7.	Manganese	mg/l	0.1	0.1	0	0.05 (0.02)
8.	Copper	mg/l	1	1	1.0	3.0
9.	Sulphates	mg/l	50	250 (500)	250	250 (25)
10.	Chlorides	mg/l	350	250 (350)	250	– (25)
11.	Zinc	mg/l	5	–	3.0	0.1 – 5.0
12.	Nitrates	mg/l	45.0	45	50	30.0 (25.0)
13.	Nitrites	mg/l	–	–	3.0	1.0
14.	Potassium	mg/l	–	–	–	150
15.	Calcium	mg/l	–	–	–	100
16.	Magnesium	mg/l	–	10	–	50
17.	Total alkalinity	mg/l	–	0.5 – 6.5	–	–
Chemicals added and formed during water treatment						
1.	Total residual active chlorine	mg/l	0.3 – 0.5	0.3 – 0.5	0.6 – 1.0	–
2.	Trigalomethanes: bromoform dibromochloromethane chloroform carbon tetrachloride	mg/l	 –	Total 0.1, including: 0.01 0.06 0.002	 0.1 0 0.06	 – 0.015 0.04
3.	Residual ozone	mg/l	0.1 – 0.3	0.1 – 0.3	–	–
4.	Formaldehyde	mg/l	–	–	0.9	–
5.	Polyacrylamide	mg/l	2	–	1	Acrylamide 1
6.	Activated silicic acid	mg/l	3.5	–	–	–
7.	Polyphosphates	mg/l	–	–	–	–
8.	Silver	mg/l	–	Not standardised (approximately up to 0.1)	–	–
Integral indicators						
1.	Oxidisability	mgO_2 /l	–	4.0	–	–
2.	Total organic carbon	mgO_2 /l	–	3.0	–	–
Radiation safety indicators						
1.	Strontium-90	Bq/l	–	4.0	–	–
2.	Caesium-137	Bq/l	–	2.0	–	–
3.	Total volumetric activity of α-emitters	Bq/l	–	0.1	–	–
4.	Total volumetric activity of β-emitters	Bq/l	–	1.0	–	–

Water quality is determined by its composition and properties when it enters the water supply network and at the points of water intake of the external and internal networks. The epidemiological safety of water is determined by the number of microorganisms and bacteria of the Escherichia coli group. In terms of microbiological indicators, drinking water must meet the requirements specified in Table 2.5. Toxicological indicators of water quality characterise the

harmlessness of its chemical composition and provide standards for substances that are present in natural waters, are added to water during treatment in the form of reagents, and appear as a result of contamination of water sources. The concentration of chemicals in natural waters or added to water during treatment must not exceed the standards specified in Table 5.1.

Indicators that ensure favourable organoleptic properties of water provide standards for substances contained in natural water or entering it as a result of treatment or contamination. In total, MPCs have been established for 640 substances in water for domestic and drinking purposes. In 2010, the Ministry of Health of Ukraine approved *the State Sanitary Rules and Norms (DSanPiN 2.2.4-171-10) «Hygienic requirements for drinking water intended for human consumption»,* which sets out stricter requirements for the content of pollutants and which are close in meaning to the standards of the World Health Organisation (see Table 2.5).

Water intended for sanitary purposes, washing equipment, dishes and premises of food enterprises, water supply to laboratories and drinking must meet the requirements for domestic and drinking water. The use of water with increased hardness or increased mineral salt content complicates the washing of equipment, containers and production premises. If the iron content is high, the water has an unpleasant taste, and rust stains remain on washed items. The presence of aggressive carbon dioxide in the water causes corrosion, which leads to rapid wear of pipelines.

Water used for steam boilers

Water used for steam boilers must not contain hardness salts, suspended solids or oxygen. The transparency of water for steam boilers is usually not less than 50 cm in font size, i.e. greater than the transparency of drinking water. These requirements provide for the treatment of water supplied to the enterprise from surface reservoirs or wells. The quality of the water must meet the requirements determined by the design of the boiler and the equipment that uses steam. The higher the surface tension of the boiler and the higher the steam pressure, the more thorough the treatment must be. The purpose of treatment is to prevent the formation of scale, corrosion of boilers, communications, collectors, as well as deposits in heaters, fittings, and steam turbine blades.

Boiler scale is formed due to the content of hardness salts (sulphates, chlorides, silicates and calcium and magnesium hydrocarbonates) and also contains iron and manganese oxides. Corrosion is caused by gases dissolved in water (oxygen, ammonia, carbon dioxide, hydrogen sulphide) and organic substances. Sodium bicarbonate ($NaHCO_3$) and sodium hydroxide dissolved in water cause ageing of boiler steel and corrosion of boiler fittings made of non-ferrous metals.

Heat exchange water

The main purpose of heat exchange water is to remove heat from equipment. The lower the water temperature, the lower its consumption and the greater the

amount of heat it removes. Water used for cooling must not contain suspended substances that, when deposited on the cooled surface, inhibit heat exchange and create resistance to water flow. Water used for cooling must not contain microorganisms that can lead to incrustations in the form of slime in refrigerators.

Water used for barometric condensers and evaporators operating under reduced pressure must meet the microbiological requirements for drinking water. In terms of chemical composition, it must not be capable of releasing or dissolving calcium carbonate deposits. Water must remain stable in terms of temperature, dry residue, carbonate hardness and calcium ion content. If the pH of the water is equal to the pH at saturation, the water is stable; if lower, the water has corrosive properties; if higher, calcium carbonate sediment is released, which settles on the walls of the heat exchange equipment.

5.3. Drinking water treatment technology

When the quality of water from natural sources, both surface and underground, does not meet consumer requirements, it must be purified. The chemical composition and properties of natural water and consumer requirements determine the choice of water treatment methods. L.A. Kulsky proposed a classification of impurities according to their phase-disperse state, which made it possible to provide a scientific justification for technological methods of water treatment. The basic principles of this classification are as follows:

- the phase-disperse state of water impurities determines their behaviour during water treatment;
- each phase-disperse state corresponds to a specific set of water treatment methods, which makes it possible to achieve the required water quality.

To remove impurities of the first group from water – suspended (suspensions and emulsions, as well as microorganisms and plankton) with a size of 10^{-2} – 10^{-4}cm, the following processes are recommended: mechanical separation in a gravitational field or under the action of centrifugal forces, as well as filtration through porous media and fine screens; adhesion using highly dispersed and granular materials, as well as aluminium or iron hydroxides and clay minerals; aggregation with flocculants; flotation of impurities, etc.; bactericidal treatment for pathogenic microorganisms.

When preparing drinking water from surface water bodies, it is usually clarified, decolorised and disinfected. If these water sources are underground, pressurised or unpressurised waters or water from clean lakes, its preparation is limited to disinfection only.

The design of the technological scheme is determined by the capacity and composition of the planned structures, the relief and hydrogeology of the site, climatic conditions and the possibility of creating sanitary protection zones, as well as technical and economic calculations. According to the principle of water mass movement in treatment facilities, there are gravity and pressure systems. The former use open-type structures. The treated water flows in them by gravity due to the difference in hydrostatic levels both in different parts of the structures and between individual structures.

In some cases, to eliminate persistent unpleasant odours and tastes, and to destroy plankton, double chlorination of water with increased doses of chlorine is required, and sometimes dechlorination. In this case, primary chlorination is carried out in the water intake well or at the first lift pumping station. After clarification at the end of the settling tank or after the filters, secondary chlorination is carried out. Excess chlorine is removed by adsorption filters filled with granulated activated carbon.

In pressure systems used to treat small amounts of water, the relative height of individual structures is irrelevant, and the pressure loss in such installations consists of the sum of pressure losses in individual structures and pipelines. Water treatment plants must operate continuously. The layout of the treatment facilities includes a bypass line that allows water to be supplied directly to clean water reservoirs (CWR), bypassing the treatment facilities. This is provided for in case of emergencies.

The clarification of natural water from centralised water supply is usually carried out in settling tanks, where suspended particles settle under the action of gravity, and in filters or clarifiers of various designs (contact and suspended layer). Modern sedimentation tanks are flow-through, as the sedimentation of suspended solids in them occurs with the continuous movement of water from the inlet to the outlet. Therefore, the speed of water movement in sedimentation tanks is insignificant. It is a fraction of a millimetre per second in vertical sedimentation tanks and several millimetres per second in horizontal, thin-layer and radial sedimentation tanks.

The purification of natural waters from colloidal-disperse impurities, which are characterised by high aggregative and sedimentation stability, is carried out by coagulation under the action of coagulants, flocculants and their mixtures. Low-molecular-weight inorganic or organic electrolytes that cause particle aggregation are called coagulants. *Coagulants* are hydrolysable salts, such as sulphates or halides of multivalent cations, mainly aluminium and iron. *Flocculants* are inorganic and organic high-molecular compounds that promote the formation of aggregates by combining several particles through macromolecules of adsorbed or chemically bound polymer.

Thus, the essence of the process of coagulation of water from colloidal-disperse substances lies in reducing the aggregate stability of disperse systems by aggregating the particles of the disperse phase under the action of coagulants (coagulants and flocculants) with subsequent separation of the particles by settling, filtration, centrifugation and other methods.

The aluminium aquahydroxocomplexes formed in stages I and II of hydrolysis aggregate into dimers, tetramers and multinuclear complexes. The latter eventually combine into large-disperse aggregates of aluminium hydroxide, on which impurities – contaminants of the treated water – are sorbed. The size of these aggregates, which settle in sedimentation tanks under the action of gravity, is several hundred micrometres and even several millimetres.

One of the most important technological parameters of the water purification process by coagulation is the coagulant dose. Its optimal value depends on the

properties of the dispersed system (water being purified): temperature, amount of suspended and colloidal-dispersed substances, colour, ionic composition of water, pH value and other physicochemical indicators. If the coagulant dose is insufficient, the desired purification effect will not be achieved, and an excess of coagulant, along with the overuse of expensive reagents, may in some cases worsen coagulation. At $4.5 > pH > 8.5$, there is an increased content of residual aluminium in the treated water due to the formation of soluble basic aluminium sulphates at $pH < 4.5$ or sodium aluminate at $pH > 8.5$.

After clarification, the water undergoes control filtration in filters with granular fill. Filters are classified according to filtration speed as slow (0.5 m/h), fast (2 – 15 m/h) and ultra-fast (over 25 m/h). The filter material is most often quartz sand, ceramic gravel, marble, crushed anthracite, dolomite, magnesite, expanded clay, rock, porous plastics (polystyrene, polyurethane), etc. Open pressure and multilayer filters are used. Two-layer filters have become widespread, in which anthracite, expanded clay, polystyrene are used as filter material, and granite, sand, magnetite, etc. are used as a support layer. The filtration rate in them is 10 – 25 m/h.

The final stage of water treatment for domestic and drinking purposes is disinfection.

All disinfection methods can be classified into four main groups: thermal; using strong oxidants; oligodynamics (the action of noble metal ions – silver, etc.); physical (using ultrasound, radioactive and ultraviolet radiation). Of these methods, oxidation methods are the most widely used. Chlorine, chlorine dioxide, ozone, and, less commonly, iodine, potassium permanganate, hydrogen peroxide, sodium hypochlorite, and calcium hypochlorite are used as oxidants. Recently, disinfection with ultraviolet radiation has become widespread in low-capacity treatment plants.

The choice of water disinfection method is based on the flow rate and quality of the water being treated, the effectiveness of its preliminary treatment, the conditions of supply, transportation and storage of reagents, the possibility of process automation and mechanisation of labour-intensive work.

For water disinfection by chlorination, water treatment plants use chlorinated lime, chlorine and its derivatives, which kill bacteria in the water. Satisfactory chlorination is achieved by intensive mixing of water with the oxidising agent. Water chlorination is carried out with gaseous chlorine. At small water treatment complexes (up to 300 m^3/day), the use of chlorinated lime is permitted.

Chlorination of water is a reliable means of preventing the spread of epidemics, since most pathogenic bacteria (typhoid, tuberculosis and dysentery bacilli, cholera vibrios, polio and encephalitis viruses, etc.) are not resistant to chlorine. Chlorine does not destroy spore-forming bacteria, which is one of the disadvantages of this method. Another disadvantage of this method is the formation of toxic chlorine derivatives.

Ozone is an extremely strong oxidant that destroys bacteria, spores and viruses (in particular, polio viruses). Another advantage of ozonation is that, along with disinfection, it also decolorises, deodorises and improves the taste of water.

Ozone does not alter the natural properties of water, as its excess (unreacted ozone) turns into oxygen within a few minutes.

Ozone (O_3) for ozonation is obtained from atmospheric air in ozonators as a result of the action of a «quiet» (scattered without sparks) electric discharge on oxygen. The air supplied to the ozonators is first freed from moisture and dust. Dust is removed in fabric filters. Moisture is captured in adsorbers loaded with silica gel. To reduce the air temperature, it is cooled in a heat exchanger.

Ozone is fed into the water through ejectors or a set of porous tubes. The ozone dose depends on the intended use of the water. For disinfecting water from surface sources, an ozone dose of 1 – 3 mg/dm³ is used, and for groundwater, 0.75 – 1 mg/dm³. For water decolorisation and disinfection, the ozone dose can reach up to 4 mg/dm^3. The duration of contact between water and ozone is 5 – 10 minutes.

5.4. Special water treatment methods

As mentioned above, a number of water consumers in the food industry have specific requirements for water: lower hardness salt content (softened water), lower iron, manganese, fluoride or silicate content, etc. However, natural water often has an elevated content of these substances or a content that does not meet consumer requirements. Such water must be softened or purified.

Water softening

Water softening is understood as the process of removing hardness cations, i.e. calcium and magnesium, from water. According to the state standard, the hardness of domestic and drinking water should not exceed 7 mmol/dm^3. Certain types of production have more stringent requirements for process water (0.05 – 0.01 mmol/dm^3.

The following methods are used to soften water: thermal, reagent, ion exchange, dialysis, and combined. The thermal method involves heating, distilling or freezing water. Reagent methods are based on the fact that Ca^{2+} and Mg^{2+} ions contained in water are converted into practically insoluble compounds using certain reagents. Ion exchange is based on filtering water through ion exchange resins, which exchange K^+ or H^+ ions of the ion exchange resin for Ca^{2+} or Mg^{2+} ions of the softened water. Water softening by dialysis is based on different rates of diffusion of hardness salts through a semi-permeable membrane that separates concentrated and diluted solutions. Under the action of the concentration gradient, dissolved salts diffuse through the membrane at different rates. The solvent (water) diffuses in the opposite direction, reducing the rate of transfer of dissolved substances. Combined methods are various combinations of the methods listed in.

The choice of water softening method is determined by its quality, the required degree of softening, and technical and economic considerations. According to DSanPiN 2.2.4-171-10, ion exchange methods are used to soften groundwater. For softening surface water, when both purification and clarification of water are required, the lime or lime-soda method is used, and in the case of

deep water softening, further cationisation is used.

Removal of iron and manganese from water

Two methods are used to remove iron from water: reagent and non-reagent.

Reagent methods include: simplified aeration, oxidation, filtration; pressure flotation with liming and subsequent filtration; liming, settling in a thin-layer clarifier and filtration; filtration through modified loading; electrocoagulation; cationisation. Deferrization of surface water can only be carried out using reagent methods, while reagent-free methods are most widely used to remove iron from groundwater.

Reagent-free methods include vacuum-jet aeration and filtration; simplified aeration and filtration, dry filtration, filtration on frame filters; filtration in underground conditions with prior injection of oxidised water or air into the aquifer; aeration and two-stage filtration.

Manganese is removed from water by treating it with potassium permanganate; aeration with alkali; filtration through coarse sand or cationite; oxidation with ozone, chlorine or chlorine (IV) oxide. Manganese removal from surface water with potassium permanganate is carried out simultaneously with other water treatment methods (coagulation, filtration, etc.). A solution of potassium permanganate is fed into the pipeline of the first lift pumping station before coagulation.

To remove manganese from groundwater, open pressure (cationic) filters are used, loaded to a height of 1.2 m with sand with a grain size of 1 – 2 mm. The degree of water purification is 95 – 99 %. Manganese (II) ions can be removed from water using Na-cation filters. Manganese is completely removed during water ozonation. Oxidation results in the formation of poorly soluble manganese (IV) oxide, which is removed from the water during filtration through granular filters.

Removal of salicylic acid from water

Water with a low salicylic acid content is used in steam boilers, in the alcohol and chemical-pharmaceutical industries, and in other sectors. To reduce the salicylic acid content, the following methods are used: precipitation, sorption, ion exchange, and electrochemical treatment. Lime, iron and aluminium salts, magnesium hydroxide, burnt dolomite, caustic magnesite, anionites, and electrolysers with a soluble anode are used for this purpose.

When lime is used, calcium silicate solubility is achieved. With an excess of lime and an increase in temperature, the degree of removal increases. The method of using iron salts is based on the ability of iron (III) hydroxide flakes, which are formed during the hydrolysis of iron salts, to sorb molecularly dispersed and colloidal salicylic acid. When aluminium salts (mainly aluminium sulphate) and sodium aluminate are used, aluminium hydroxide is formed, which acts as a sorbent.

Salicylic acid can be removed from water by filtering it through activated filters. The filters are loaded with magnesia sorbents (semi-calcined dolomite,

treated caustic magnesite, bauxite, activated aluminium oxide). In this case, the salicylic acid content is 0.1 – 0.3 mg/dm^3.

The anion exchange method of salicylic acid removal reduces the SiO_2^{2-} content to 0.03 – 0.05 mg/dm³. The essence of the anion exchange method is that water is passed through H-cation exchange filters, where Ca^{2+}, Mg^{2+}, K^+, and Na^+ cations are removed from it. The water then passes through filters with weakly basic anionite, where strong acid anions (SO_4^{2-}, Cl^-, NO_2^-) are removed. After degassing the water (removing CO_2), it is passed through filters with strongly basic anionite, where weak salicylic acid is removed. To obtain water with a total salicylic acid content of less than 0.03 mg/dm^3, three-stage ionisation schemes are used. The disadvantage of this method is its high cost.

Fluoridation and defluoridation of water

The cause of fluorosis is an elevated fluoride content in drinking water (more than 1.5 mg/dm^3). A fluoride content in water of less than 0.1 – 0.2 mg/dm³ leads to the development of caries. The optimal concentration of fluoride in drinking water is 0.7–1.2 mg/dm^3. If the fluoride content in water sources is less than 0.5 mg/dm^3, the water is fluoridated, and if it is greater than the optimal dose (more than 1.5 mg/dm^3), it is defluoridated.

To fluoridate water, water-soluble fluorine compounds are added to it (K_2SIF_6, $(NH_4)_2SIF_6$, $A1_2(SIF_6)_3$, NaF, $A1F_3$, etc.). They are added to the water before chlorination.

All methods of water defluorination can be divided into two groups. The first group includes the method of fluorine sorption by aluminium and magnesium hydroxide precipitates and calcium phosphate. This method is used for the treatment of surface natural waters when, in addition to defluorination, clarification and decolourisation are also required. The second group includes methods of filtering water through fluorine-selective materials. They are based on ion exchange sorption, in which fluorine is removed by passing water with a high fluorine content through a sorbent. This method is effective for defluorination of groundwater when desalination is performed simultaneously with defluorination. Strong base cation exchangers and anion exchangers are used for this purpose.

Purification of water from radionuclides

Radioactive contamination of water is characterised by a wide variety of radionuclides. The most dangerous are strontium-90 and caesium-137.

Methods of water decontamination are divided into physical-chemical (distillation, precipitation, coagulation, flotation, filtration, sorption, ion exchange, extraction, evaporation), electrolytic (electrolysis, electrodialysis, electroionisation), biological and combined (a combination of the above methods). Coagulation has a decontaminating effect at higher doses of reagents if radioactive substances are in a colloidal state or adsorbed on natural coarse-grained impurities. If radionuclides are in a dissolved state, water decontamination by coagulation does not achieve the desired result.

The decontaminating effect of the coagulation process depends on the

properties of radioactive isotopes, their concentration, the nature of coagulants, their dose and other factors. The following coagulants are recommended for decontamination: sulphates and chlorides of aluminium and iron (III), sodium and potassium phosphates, a mixture of lime and soda with sodium silicate. The most effective coagulants are basic sulphates and chlorides of aluminium. Decontamination of water by coagulation, settling and filtration reduces the radioactivity of water by 50 – 70 %, and in the case of aluminium hydroxosulphates, by more than 90%.

Removing radionuclides from water with sorbents is one of the most common methods of decontamination. The following are used as sorbents natural ion-exchange substances (clays, clinoptilolite, hydromica, soils, bentonite and other natural zeolites and minerals); artificial inorganic sorbents (based on poorly soluble salts of titanium, zirconium, heteropolyacids, synthetic zeolites, silica gel, metal powders); natural organic sorbents (peat, humic substances, wood, cellulose, activated carbon, etc.).

Distillation is one of the most reliable methods of water decontamination if the radioactive substances are non-volatile. If volatile radionuclides are present in the water, they must be precipitated or converted to a bound state before distillation. This method is suitable for decontaminating small amounts of water. Electrodialysis is also used to remove radionuclides in ionic form from water.

5.5. Water drainage and sewage systems of industrial enterprises

Water used in technological processes, as well as storm and melt water from the enterprise's territory, is removed through a drainage system (sewerage) to municipal treatment facilities.

The water drainage system includes the following main elements: internal water drainage systems in industrial premises, internal site water drainage networks; regulating reservoirs; pumping stations and pressure pipelines; treatment facilities; discharge of treated wastewater into water bodies.

Drainage systems are divided into combined, separate and combined. In turn, separate systems are divided into fully separate, partially separate and semi-separate. A combined drainage system has a single drainage network designed to drain wastewater of all categories: domestic, industrial and storm water. Wastewater drainage is arranged in such a way as to prevent the main collector from overflowing during heavy rainfall.

A complete separate drainage system has two or more collectors designed to separately drain wastewater of a certain category. Industrial wastewater is treated at special treatment facilities of a specific industrial facility or group of such facilities. After treatment, industrial wastewater is used for technical water supply, sent to municipal treatment facilities for further treatment, or discharged into a water body.

An incomplete separate drainage system involves the drainage of domestic and industrial wastewater through a single collector. Usually, an incomplete separate system is used for small drainage facilities and is the initial stage in the

creation of a complete system. A semi-separate drainage system involves the discharge of a mixture of domestic wastewater through a single common collector and rainwater through another. A combined drainage system is a combination of a combined system and a complete separate system.

A complete set of municipal treatment facilities includes units for mechanical and biological treatment, secondary treatment, disinfection, and sludge treatment. Mechanical treatment removes large inclusions from wastewater, which are crushed in crushers if necessary. The removed large inclusions are transported to a landfill site. Suspended solids are deposited in sand traps, and the sediment is sent to sand pits. After drying, it can be used for levelling work.

In pre-aerators, wastewater undergoes primary oxygen saturation, which improves the biological treatment process, as well as purification from petroleum products and other floating impurities. From the primary sedimentation tanks, the water enters the biological treatment unit, where organic compounds are destroyed as a result of biochemical reactions. Of the biological treatment facilities, aerotanks are the most widely used**.** From the aerotanks, the wastewater flows into secondary sedimentation tanks, where active sludge settles (Fig. 5.1).



Fig. 5.1. Bortnytska aeration station [22]

After the secondary settling tanks, the treated wastewater is disinfected by chlorination. After chlorination, the water undergoes degassing. The latter takes place in channels along the path of the water, which is discharged into a water body. If the quality of the wastewater does not meet the requirements for discharge into water bodies, or if the treated wastewater is to be used for technical water supply or to fill urban rivers, additional treatment is organised.

For additional treatment of wastewater, filters with granular filling, foam and pressure flotation units, coagulation, sorption, ozonation, and units for removing phosphorus and nitrogen from water are used. To give treated wastewater the quality of natural water, its additional treatment is carried out in a cascade of

biological ponds or in bioengineering structures such as bioplatforms.

During the biological treatment of wastewater, a large amount of sludge is formed, which is dead or excess active sludge. It is removed from aeration tanks and secondary clarifiers. It has a moisture content of 97 – 98 % and is very difficult to dewater. For the purpose of dewatering, it is first treated in methane tanks or aerobic stabilisers, then subjected to mechanical dewatering in hydrocyclones, centrifuges, vacuum filters or filter presses, after which it is sent to sludge beds for final drying. Here, under natural conditions, the sludge sediment is dried and composted (decomposed) over several months. Composted sludge sediment is an effective organic fertiliser. Restrictions on its use are related to its high heavy metal content.

5.6. Conditions for wastewater discharge

Industrial wastewater is usually treated at the enterprise (the vast majority of food enterprises in Ukraine do not have their own treatment facilities) and can then be reused by the enterprise, transferred to another enterprise for use, discharged into a water body, or sent through the drainage system to municipal treatment facilities. The required degree of treatment of municipal wastewater is determined by the conditions for discharging wastewater into water bodies. However, the treatment capacity of municipal treatment facilities is limited. In addition, the content of substances that do not undergo or are difficult to undergo biochemical oxidation is limited in industrial wastewater supplied to municipal treatment facilities. Impurities must not affect active sludge, destroy or clog sewer collectors.

Based on these prerequisites, it is prohibited to discharge wastewater into municipal drainage systems:

- with a pH of less than 4.0 and more than 9.0;
- whose COD is more than 2.5 times higher than BOC_5 or more than 1.5 times higher than BOC_{total}. Otherwise, wastewater may contain a significant amount of organic compounds that do not undergo biochemical oxidation;
- which contain toxic and radioactive substances, infectious disease pathogens, as well as substances for which no MPC has been established;
- with a content of suspended and floating substances exceeding 500 mg/dm^3;
- with a temperature higher than 40°^{0}C.

It is prohibited to discharge the following into urban wastewater systems:

- concentrated stock and working solutions;
- sludge from local treatment facilities, soil, construction and household waste, industrial waste;
- acids, alkalis, solvents, resins, petrol, fuel oil and other petroleum products;
- solutions containing hydrogen sulphide, carbon disulphide, volatile

hydrocarbons;

- substances that can clog pipes, wells, grates or settle on pipe walls;
- combustible impurities and dissolved gaseous substances capable of forming explosive mixtures, aggressive gases with a destructive corrosive effect on sewerage networks and structures.

The discharge of industrial wastewater into the municipal drainage system must be carried out evenly throughout the day. Bulk discharges are prohibited.

The discharge of wastewater into water bodies after treatment at municipal treatment facilities is regulated by maximum permissible discharge (MPD) standards for pollutants.

Given the limited treatment capacity of municipal treatment facilities, the management of these facilities sets limits on the quantity and composition of wastewater discharges for their subscribers – enterprises. The limits are set in such a way as to ensure the regulatory conditions for the discharge of wastewater treated at municipal treatment facilities into water bodies. In order to comply with the limits set for each enterprise, local treatment of industrial wastewater is carried out, as a rule, at the enterprise itself. Sometimes several enterprises organize joint wastewater treatment.

The discharge of wastewater into water bodies is a type of special water use and is carried out on the basis of a permit issued by local environmental safety authorities. The discharge of wastewater into water bodies is regulated by the MPC standards for pollutants. MPC is the maximum permissible concentration of substances discharged with wastewater per unit of time, which makes it possible to ensure that water quality standards are maintained at the control point of a water body under the worst conditions of water use. The MPC is set for each discharge of wastewater into a water body and for each water quality indicator is determined as the product of the maximum hourly wastewater discharge and its maximum permissible value:

$$GDS = Q_{st} \times C_{gd},$$

where Q_{st} – is the maximum wastewater discharge per hour, m^3 /hour;
C_{max} – maximum permissible value, g/m^3.

The initial data for calculating the GDS are:

- type of water body – wastewater receiver;
- calculated value of background concentration; dilution factor of wastewater corresponding to the worst hydrogeological conditions;
- type of discharge;
- actual (design) value of the concentration of pollutants in wastewater;
- approved maximum wastewater discharge rate per hour.

The conditions for discharging wastewater into flowing and non-flowing water bodies are different. Compliance with scientifically based standards for discharging wastewater into water bodies should ensure effective self-purification of water. The ratios given below allow only a rough estimate of the conditions for

discharging wastewater.

For flowing water bodies, the condition for wastewater discharge in terms of the normative indicator of harmful impurities is determined by the formula

$$C_z \cdot q + C_{zv} \cdot a \cdot Q_t \leq (a \cdot Q + q) \cdot C_{MPC},$$

where C_z – is the concentration of pollutants in wastewater that must be achieved as a result of treatment;

C_{zv} – concentration of the same type of pollutants in the water body prior to wastewater discharge;

C_{MPC} – maximum permissible concentration of pollutants;

a – mixing coefficient reflecting the proportion of water in the reservoir that mixes with wastewater in the calculated water discharge;

Q – water flow in the reservoir, m^3 /hour;

q – wastewater flow entering the water body, m^3/year.

The value of Q is determined based on data from the hydrometeorological service, q – based on technological calculations, and C_{zv} – based on field measurements or reference data. The mixing coefficient a depends on many factors: the design of the outlet, the distance to the calculated discharge, the hydraulic characteristics of the flow and the hydrological parameters of the reservoir.

The conditions for discharging wastewater into a non-flowing reservoir are determined by the ratio

$$C_z \leq C_z + n_p \cdot (C_{MPC} - C_z),$$

where n_p – the multiplicity of the smallest dilution.

Dividing both parts of the inequality by q, we get

$$C_z + C_{zv} \frac{aQ}{q} \leq \left(\frac{aQ+q}{q}\right) \cdot C_{MPC}$$

The expression in brackets means the dilution factor in flowing water bodies. Then the values of n_p and a are determined by the expressions

$$n_p = (aQ + q)/q;$$

$$a = (n_p - q)/Q$$

Substituting the value of a into the previous formula, we have

$$C_z + (n_p - 1)\, C_{link} \frac{aQ}{q} \leq n_p \cdot C_{MPC}$$

Analysis of the equation proves that in the absence of a certain type of pollutant in a flowing water body, this expression takes the form

$$C_z \leq n_p \cdot C_{MPC}$$

I.e. the concentration of pollutants in wastewater must be equal to or less than the product of the dilution factor and the MPC. In other words, the dilution factor must be such that the concentration of pollutants in the flowing water body does not exceed the maximum permissible concentration.

If the concentration of pollutants in the water body C_{zv} increases over time (when the discharged pollutants decompose slowly), dilution can be neglected (the expression in brackets is equal to or close to 0), and the previous formula takes the form $C_z \leq C_{zv}$. In this case, wastewater must be treated to a concentration lower than the MPC.

The required degree of wastewater treatment from suspended solids D_z and by the value of BOC_{TOTAL} = E in percent is determined by the formulas:

$$D_z = (C - C_{additional})/C;$$

$$E = (B_a - B_{water})/B_a .$$

where C – is the amount of suspended solids in the wastewater before treatment, g/m^3;
$C_{доп}$ – permissible content of suspended solids in wastewater, g/m^3;
B_a – actual BOC_{total} in the discharged water;
B_{water} – BOC_{total} to be achieved during treatment.

If the wastewater has an acidic or alkaline reaction, the neutralising capacity of the water body should be taken into account. This sometimes makes it possible to do without special wastewater neutralisation facilities. According to sanitary regulations, in water bodies of all types of use, in the case of calculated wastewater discharge, the change in pH should not exceed 6.5 – 8.5. The permissible acid or alkali content in wastewater discharged into a water body is determined by the equation

$$C_{st.k} = (n - 1)C_k \; ; \; C_{st.l} = (n - 1)C_l ,$$

where C_k, C_l – maximum amount of acid or alkali in 1 ml of normal solution, which can neutralise 1 litre of water, provided that in the case of calculated wastewater discharge, the pH of the water remains within sanitary requirements.

The permissible values of temperature, colour, odour, salt composition, and dissolved oxygen content in the water of the reservoir that mixes with wastewater are determined experimentally.

5.7. Wastewater treatment

To meet all of the above requirements, wastewater must be treated before being discharged into water bodies. All treatment methods are divided into three main groups: mechanical and mechanochemical, chemical and physicochemical, and biochemical (biological). The technology for treating wastewater from impurities is based on processes that occur under the action of forces that most effectively affect this dispersed system.

Settling is used to remove coarse impurities from wastewater, such as clay particles with a concentration of up to 500 mg/dm^3, which may have a colour of 50 degrees, in settling tanks of various designs: vertical, horizontal and radial. Horizontal settling tanks are used for wastewater flows of up to 20,000 m³ per day, and radial settling tanks are used for flows of over 20,000 m³ per day.

Slow filters are designed to remove suspended solids up to 50 mg/dm³ from water with a colour of up to 50 degrees. Preliminary filters are used to remove suspended impurities with a content of up to 1000 mg/dm³. Plankton with a content of more than 1000 cells/cm³ and suspended solids are removed using microfilters, while coarse impurities are removed using continuously operating centrifuges and hydrocyclones. Floating is used to clean wastewater from petroleum products in oil traps and from grease in grease traps. For these purposes, flotation machines and devices for dispersing air and flotation using reagents are also used.

Colloidal impurities and high-molecular substances are removed using dialysis, ultrafiltration, chlorine oxidation, coagulation of colloidal impurities, adsorption on aluminium or iron hydroxides, as well as on highly dispersed clay materials, electrophoresis and electrodialysis. Suspended colloidal-dispersed substances are removed by ultrafiltration through large-pore membranes. Coagulation is used to remove the finest colloidal-dispersed clay particles, protein substances and other high-molecular compounds from wastewater. Organic substances are removed by adsorption, usually in combination with other methods; in particular, mechanical methods or coagulation are used to remove coarse-dispersed impurities.

Molecularly soluble impurities and gases are removed from water by desorption of gases and distillation of volatile organic compounds (phenols, etc.) during aeration using spray basins, aerators and degassers of various types. Additional purification from hydrogen sulphide after aeration, as well as from volatile organic compounds with low chlorination efficiency, is carried out by oxidation using chlorine, ozone, potassium permanganate and other oxidants. Phenols and other organic compounds can be removed from wastewater by extraction.

Since industrial wastewater from the food industry mainly contains biochemically easily oxidisable pollutants – proteins, fats and carbohydrates – the biochemical method has become the most widely used for treating such water. Biochemical (biological) treatment methods are based on the use of various microorganisms. There are two types of processes: aerobic, which takes place in the presence of oxygen, and anaerobic, which takes place without oxygen.

Anaerobic treatment is used as the first stage in preparation for further aerobic treatment of wastewater with a high concentration of organic pollutants.

The most common method of biological treatment is biochemical oxidation of wastewater in aerotanks using activated sludge (Fig. 5.2). Microorganisms feed on organic substances in wastewater, breaking them down with their own enzymes that decompose carbohydrates, proteins and fats. Organic impurities in wastewater are used as material for building the bodies of microorganisms and obtaining the energy necessary for their vital functions. At the beginning of the destruction of organic substances, active sludge bacteria multiply intensively. Then more complex organisms begin to develop – ciliates, rotifers, nematodes, etc. Ciliates feed on bacteria.



Fig. 5.2. Biochemical oxidation of wastewater in aerotanks [23]

All strains of bacteria isolated from different sludges use mineral nitrogen, and many of them are capable of denitrification. The most common types of bacteria are: Pseudomonas (50 – 80 %), Bacillus bacterium (8 – 33 %), Sardina and Micrococcus. In terms of species, the bacteria isolated from different sludges are the same. There are many common species, which indicates that heterotrophic bacteria have different types of metabolism. This leads to the rapid adaptation of active sludge during the treatment of various types of wastewater. At the same time, the number of microorganisms in active sludge can vary significantly depending on the composition of the wastewater.

The main favourable environmental conditions for the destruction of organic substances in wastewater by activated sludge are aeration, a temperature of 15 to 25 – 30°⁰C, the presence of a flow and a pH of between 7.0 and 8.0. However, in some cases, biochemical wastewater treatment is possible at pH values of 6 and 9 – 11 and at temperatures of 2 – 3°⁰C.

Biological aerobic treatment is carried out in biofilters, aerotanks, on irrigation fields and in biological ponds. Biofilters are constructed in the form of reinforced concrete tanks with a diameter of up to 30 m and a height of: low –

1.5 – 2; high – 2 – 4; tower – 10 – 20. Gravel, pebbles, expanded clay or plastic grid blocks are placed on the bottom of the tank with holes. Microorganisms that feed on organic impurities in wastewater colonise the surface of the laid materials. Microorganisms convert organic substances into inorganic ones (mainly carbon dioxide and water or methane, ammonia, etc.). Biofilters are suitable for use in areas with a warm climate for wastewater with a BOC of no more than 400 – 500 mg O_2/dm^3.

When treating wastewater from the food industry, which is usually characterised by a high content of easily oxidisable organic substances, low concentrations of mineral salts and a sufficient content of biogenic elements (nitrogen, phosphorus, potassium), the main technological elements of treatment facilities are aerotanks.

Aerotanks are tanks up to 100 m long and more, up to 10 m wide and up to 5 m deep, into which air is constantly pumped. Wastewater is treated using the "pure culture" method or with the help of activated sludge. "Pure culture" refers to cultivated populations of microorganisms that feed on certain substances (mainly of organic origin). The growth of activated sludge is periodically removed from the apparatus and, after disinfection, can be used as fertiliser.

Wastewater enters the aeration tanks, usually after mechanical treatment. The concentration of suspended solids in them should not exceed 150 mg/dm^3, and the permissible $\mathbf{BOC}_{total}$ depends on the type of aeration tank. When treating a mixture of industrial and domestic wastewater, the requirements for the active reaction of the medium, temperature, salt composition, presence of harmful substances, oils, biogenic elements, etc. must be maintained. To ensure the normal course of the biological oxidation process, air must be supplied to the aeration tank, which is achieved by means of a pneumatic, mechanical or pneumatic-mechanical aeration system.

Aerotanks can be single-stage or two-stage. In both cases, they are used with or without regeneration (Fig. 3.3).



Fig. 5.3. Aerotank for deep wastewater treatment [24]

Single-stage aerotanks without regeneration are used for **BOC**$_{total}$ of wastewater not exceeding 150 mgO_2/dm^3, with regeneration – more than 150 mgO_2/dm^3 and in the presence of harmful industrial impurities. Two-stage aerotanks are used for the treatment of highly concentrated wastewater.

In wastewater treatment practice, multi-chamber aerotanks and oxytenks are also used. A multi-chamber aerotank is a conventional aerotank divided lengthwise into several chambers (usually five to nine) of equal volume, which prevents longitudinal mixing. The oxidation capacity of oxy-tanks is several times greater than that of conventional aeration tanks, and the sludge dose reaches 6 – 10 g/dm^3.

Depending on the structure of the wastewater and recycled active sludge flow, the following types are distinguished:

- *aerotanks-extruders* – wastewater and recycled active sludge are fed concentrated from one of the end sides of the aerotank and are also discharged concentrated from the opposite end side;
- *mixing aeration tanks* – wastewater and sludge are fed and discharged evenly along the long sides of the aeration tank corridor;
- *aeration tanks with dispersed wastewater feed* – wastewater is fed at several points along the length of the aeration tank and discharged in a concentrated manner from its end; return sludge is fed in a concentrated manner at the beginning of the aeration tank.

Aerotanks are used in an extremely wide range of wastewater flows, from several hundred to millions of cubic metres per day.

Extrusion aeration tanks are suitable for use with **BOC**$_{total}$ water up to 300 mgO_2/dm^3, and mixing aeration tanks for **BOC** $_{total}$ up to 1000 mg O_2/dm^3.

Large, expensive treatment facilities are required to treat wastewater with a high content of pollutants (**BOC**$_{POOUT}$> 2000 mg O_2/dm^3) using aerobic biochemical processes. In order to save money, it is advisable to pre-treat wastewater using aerobic fermentation in methane tanks. Virtually any substance of plant or animal origin can be used as a substrate. This removes a significant proportion of organic pollutants. By combining these two methods (anaerobic and aerobic), it is possible to achieve 95 – 98 % purification.

The process of anaerobic water treatment, which takes place in a bacterial mass, involves the conversion of complex organic substances – polysaccharides, lipids and proteins – into methane and carbon dioxide. In addition to natural substrates, anaerobic populations destroy phenols and sulphur-containing compounds present in wastewater. Fermentation products may vary depending on the type and strain of bacteria, the composition and amount of nutrients (water contaminants) and other cultivation parameters: pH, temperature and redox potential of the environment. The adequacy of nutrients for bacteria in water is determined by the **BOC** : N : P ratio, which should be at least 100 : 5 : 1. The optimal value of the active reaction of the environment should be within the range of pH = 6.7 – 7.5.

During methane fermentation, the gaseous product is methane, which is used as fuel. At the same time, methane fermentation is characterised by the

accumulation of a certain amount of cobalamin group vitamins, which makes it possible to use active sludge as animal feed or fertiliser.

A small amount of intermediate metabolites formed during fermentation can be eliminated by aerobic oxidation (additional purification). Therefore, the use of methane fermentation for the treatment of concentrated food industry effluents is expedient, as it allows, along with treatment, to significantly increase the efficiency of the process through the use of biogas for energy needs and biomass enriched with biologically active substances. The amount of biogas can reach 6 – 7 $dm^{3/}dm^3$. The energy of the released biogas is sufficient to fully or partially cover the energy costs of the fermentation process.

Irrigation and filtration fields and biological ponds are soil-based biological treatment methods. Various crops are grown on irrigation fields simultaneously with wastewater treatment. If no plants are grown on the sites, but only wastewater is treated, they are called filtration fields. This method is rarely used because it requires flat areas of soil that filter well, as well as special sanitary care.

Biological ponds are arranged in a cascade of 3 – 5 reservoirs with a depth of 1 – 1.5 m. Due to the slow process of biological treatment, water must remain in the ponds for at least 20 days. Biological ponds are more often used after preliminary treatment by other methods as a buffer before the reservoir into which the treated water is discharged.

5.8. Drinking water supply schemes

The simplest water supply scheme for food industry enterprises is to connect to the municipal water supply and use it to supply water to the technological process. This scheme uses an internal plant network, water intake devices and a water metering unit consisting of: a damper, a check valve, a pressure gauge for measuring pressure in the network, and a water meter. The water metering unit should also include a tap for taking water samples.

This scheme has a number of drawbacks that reduce its reliability. The lack of storage tanks makes the enterprise dependent on the operation of the municipal water supply system. During inevitable water supply interruptions due to accidents or repair work on the network, food enterprises are forced to suspend their operations. Additional water disinfection due to an unfavourable epidemic situation in the city is only possible if the scheme is modernised. Water supply interruptions may also occur due to a significant drop in pressure during peak water consumption hours in the city.

There are two possible options for the internal water supply network scheme. Option 1 (ring network) has hygienic advantages. In a dead-end network (option 2), there are sections where water stagnates, which can lead to a deterioration in its quality.

The second scheme, with water supplied from the city water supply, includes not only a clean water tank (CWT) but also pumps. This significantly stabilises the continuous water supply. At the same time, additional water disinfection is possible in accordance with epidemiological indications. In this case, the clean

water tank acts as a contact tank.

The third scheme, which includes a device for disinfecting water with ultraviolet rays, can be recommended if the enterprise takes water both from the municipal water supply and from its own source (the enterprise's artesian well) in case of a need for constant water disinfection. This scheme can only be effective if the water quality meets the necessary requirements.

The fourth scheme provides for two sources of water supply – the municipal water supply and the enterprise's artesian well. There are two possible options for this scheme, depending on which source is considered the main one and which is the backup. If the municipal water supply is the backup source, the valve on the water meter unit must be sealed in the closed position by a representative of the executive control authority. The municipal water utility and the executive control authority must be notified of the removal of the seal and the activation of the water supply. If the backup source is the enterprise's artesian well, water must be regularly pumped out to prevent deterioration in its quality. An ultraviolet installation can only be included in the scheme if the water quality of both sources is adequate.

The fifth scheme includes an autonomous water supply source, the water from which must be constantly disinfected; a chlorinator; a contact tank that provides 30 minutes of contact between water and chlorine; a clean water tank and second lift pumps. This scheme must include a mixer for mixing chlorinated water with source water before it enters the contact tank. Supplying chlorinated water directly to the tank, as is often done, does not ensure reliable water disinfection.

Each scheme involves special water treatment: deferrization, fluoridation and defluoridation, desilication, etc. These operations are included in the scheme if the chemical composition of the water from the water source requires it.

5.9. Maintenance and cleaning of the water supply system

The reliability of the water supply system in terms of epidemics largely depends on the correct implementation of its disinfection. Microbial contamination of artesian wells occurs as a result of inflow into the aquifer and suction by the well during operation, penetration from higher aquifers due to a defect in the well, inflow into the well during drilling with tools or with flushing solution and wastewater. In the first case, disinfection of the well is ineffective, as it is necessary to eliminate surface sources of contamination and wait for a certain period of time for the bacteria that have entered the aquifer to die. In the second case, repair work must be carried out before disinfection. Disinfection as a standalone measure is only justified in the third case.

Before disinfecting an artesian well, the walls of the casing pipes are mechanically cleaned with metal brushes – brushes – and the well is flushed with forced water pumping for 12 – 24 hours (until the water contamination is eliminated). Disinfection is carried out in two stages. First, the above-ground part is disinfected – from the mouth to the static level. For this purpose, a special

pneumatic cork is installed in the well a few metres below the static level and compressed air is pumped into it. The entire volume of the well above the plug is filled with a clarified solution of chlorinated lime or calcium hypochlorite with an active chlorine concentration of 50 – 100 mg/dm^3 depending on the approximate degree of contamination. After 3 – 6 hours of contact, the pneumatic cork is removed and disinfection of the underwater part of the well from the static level to the bottom begins. The concentration of active chlorine in the disinfectant solution should be at least 50 mg/dm^3. Three to five hours after mixing the chlorine lime solution with water, pumping is carried out until the chlorine odour disappears (residual chlorine approximately 0.3 mg/dm^3 and a water sample is taken from the well for control bacteriological analysis.

When installing new equipment at the pumping station or during the repair of old pumping units, they are thoroughly cleaned and washed. The pumps are disinfected by filling the housing with a clarified solution of chlorinated lime with an active chlorine concentration of 200 – 300 mg/dm^3 and holding for 1 – 1.5 hours, then rinsed during a trial run of the pumps.

Storage tanks and water towers can be disinfected by irrigation or volumetric methods. When disinfecting tank surfaces by irrigation, the bactericidal effect is determined by the concentration of chlorine in the irrigation solution. With the volumetric method, the bactericidal effect depends on the concentration of the chlorine solution and the duration of contact.

In each case of tank disinfection, it is necessary to clean and repair it beforehand. Before starting cleaning and repair, the water is drained from the tank, the valves on the pipelines are closed and sealed. After draining the water, the tank must be inspected by a commission with the participation of representatives of the ChMSEN. The same inspection is carried out after completion of all work.

The cleaning, repair and disinfection work carried out shall be recorded in a report indicating the time of removal of the seals from the tank hatches, the start and end times of the work, those responsible for the work and the persons who carried it out. The tank shall be put into operation after receiving three results of microbiological analysis of water that meet the requirements of DSanPiN 2.2.4-171-10.

If it is necessary to disinfect the internal water supply network of the enterprise, it is intensively flushed for 4–5 hours at a water flow rate in the pipes of 1.2–1.5 m/s or more. Then, a concentrated solution of chlorinated lime (active chlorine concentration 75–100 mg/dm^3 is fed into the storage tank, the water intake devices are opened, ensuring that the water is drained into the sewerage system. After chlorination, the water is pumped until the concentration of active chlorine at the most remote point of water intake is 50% of the initial concentration, all water intakes are closed and contact is ensured for 5–6 hours. After that, all water intakes are opened again and the water is pumped out until the residual chlorine concentration in the water intakes does not exceed 0.5 mg/dm^3.

5.10. Rational use of water resources

The efficiency of water use is characterised by the following criteria:

- specific water consumption rate for the production of a unit of product;
- the amount of water in circulation;
- consumption of fresh water; amount of wastewater entering biological treatment;
- the total amount of wastewater discharged into a water body;
- the conditional amount of pollutants in wastewater; the return of wastewater to production;
- technological, economic, social and environmental efficiency;
- the impact of the water management complex on the surrounding natural environment, etc.

The rational use of water resources at an industrial enterprise is characterised by the following factors:

- the extent of use of waterless technologies (enables a reduction in water consumption and the amount of wastewater);
- location of production facilities that ensure consistent multiple use of water in the technological process (enables reduction of fresh water consumption);
- the level of sophistication of local wastewater treatment methods (reduces the amount of pollution in wastewater);
- the division of the water management system into groups of local closed technical water supply systems, which enable wastewater treatment in accordance with the requirements of water recycling;
- optimisation of water supply and treatment processes (supply and distribution of water for technological production operations, regeneration of spent solutions, creation of local water recycling systems, extraction of valuable components from wastewater and their utilisation, sludge disposal, etc.);
- full utilisation of water resources of the industrial hub, including the use of wastewater from the city and industrial enterprises on irrigated land and other facilities.

When developing rational water supply systems for industrial enterprises, efforts are made to apply low-water production technologies. Water conservation measures are developed depending on its functional use. Replacing water cooling with air cooling, using dry gas and air cleaning systems and dust extraction systems, evaporative and nozzle cooling, counterflow cascade washing systems, and pneumatic and pneumohydraulic transport systems can reduce specific water consumption by an average of 20–30%. The use of automatic control and monitoring systems for water consumption processes, the consolidation of individual capacities and units, and the fight against losses and leaks make it possible to reduce water consumption by another 10–15%.

Water consumption from natural sources can also be reduced through its reuse in industry and wastewater recycling. When using wastewater, quality requirements determine the necessary degree of treatment.

In order to save water resources, recirculating water supply systems have become widespread: with water cooling; with water purification; with water purification and cooling. Recirculating water supply systems with water cooling are more commonly used and are divided into closed, semi-closed and combined systems. In a closed system, the cooling of technological products is carried out by recirculating water in closed heat exchange devices. Recirculating water is cooled by air in a closed finned radiator (radiator cooling tower). In a semi-closed system, the cooling of technological products also takes place in closed devices, but the water is cooled in a cooling tower or other coolers.

In a number of industries, desalinated or softened water is used for cooling in the production process. In this case, a combined system is used, in which desalinated or softened water is cooled by circulating water in closed heat exchange units, and circulating water is cooled in a cooling tower. In some cases, it is advisable to cool desalinated or softened water in spray coolers, which provides deeper cooling due to the contact of the spray cooler walls with the cooling return water that constantly flows from them.

Questions for discussion and self-assessment

1. Name the main consumers of water in the food industry and give a brief description of them.
2. Formulate the requirements for water quality for technological needs in food production.
3. Formulate the requirements for water for domestic use.
4. Formulate the requirements for water for energy needs.
5. Name the sanitary and toxicological characteristics of the main impurities in natural water.
6. How does water pollution affect human health?
7. What diseases arise as a result of microbiological water pollution?
8. What technological operations comprise the technology of drinking water treatment?
9. What technological schemes for the preparation of domestic and drinking water do you know?
10. How is coagulation treatment of natural water carried out?
11. Why is purified natural water chlorinated?
12. In what cases and how is water softening carried out?
13. What methods of water softening do you know?
14. How is natural water purified of radionuclides?
15. How is wastewater disposal carried out at industrial enterprises?
16. What are the requirements for discharging wastewater into municipal wastewater disposal systems?
17. What are the requirements for discharging treated effluents into water bodies?
18. Briefly describe the main methods of wastewater treatment.

19. When is biological wastewater treatment used?
20. How is biological wastewater treatment carried out?
21. Briefly describe aerobic and anaerobic methods of wastewater treatment.
22. What are the main technological schemes for wastewater treatment in aerotanks that you know?
23. What drinking water supply schemes are used in food industry enterprises?
24. How is the disinfection of water supply facilities carried out?

CHAPTER 6. REQUIREMENTS FOR WASTEWATER FROM PROCESSING ENTERPRISES

6.1. Sanitary and hygienic indicators for wastewater from processing enterprises

To assess wastewater, a number of physical, physicochemical and sanitary-bacteriological indicators are determined. Due to the complexity of the composition of wastewater and the impossibility of determining each component, indicators called total indicators are adopted, which make it possible to characterise the properties of wastewater without identifying many components. For example, the determination of organoleptic indicators (smell and colour) makes it possible to avoid quantitative determination of each substance in water.

Sanitary physical and chemical analysis of wastewater from processing enterprises involves the determination of the following indicators: temperature, colour, odour, transparency, pH value, dry residue and its loss during calcination, salt content, suspended solids and their loss during calcination, ether-soluble substances, kinetics of suspended solids precipitation, permanganate oxidisability, chemical oxygen demand (COD), biochemical oxygen demand (BOC), nitrogen (total, ammonium, nitrite, nitrate), phosphates, chlorides, sulphates, dissolved oxygen, surfactants, microbial count, coliform bacteria (CB), helminths, etc.

Temperature. This is a very important technological indicator, as it determines the viscosity and density of wastewater, which significantly affect the dynamics of the sedimentation process of suspended solids. Temperature also affects the rate of biochemical reactions during biological treatment and the solubility of oxygen.

Colour. This indicator depends on the composition of impurities. Usually, wastewater from fish processing plants has a brownish colour due to the presence of blood in the water. The colour of the water is determined after preliminary filtration or centrifugation, as wastewater always contains suspended solids that distort the colour.

Odour is an indicator that characterises the presence of aromatic impurities and dissolved gases in the water, which are formed during the decomposition of organic substances. Odour is determined qualitatively. It is described as putrid, phenolic, kerosene, chlorine, aromatic, hydrogen sulphide, earthy, fishy, etc.

pH value. The active reaction of the wastewater environment, characterised by the pH value, affects the kinetics and dynamics of physicochemical and biochemical processes during wastewater treatment. Wastewater supplied to biological treatment facilities must have a pH value between 6.5 and 8.5. Before discharging acidic or alkaline wastewater, it is first neutralised.

Dry residue. In wastewater, dry residue characterises the contamination of water with impurities in all aggregate states. It is determined by evaporating a water sample and then drying it at $105^{\circ 0}$C. The calcined residue is obtained by calcining the dry residue at $600^{\circ 0}$C. It gives an idea of the ratio of organic and

inorganic parts in the total mass of impurities.

Dense residue characterises the total amount of dissolved inorganic and organic substances. It is determined in the same way as dry residue, but from a filtered sample. The loss of mass of the dense residue during calcination characterises the ratio of inorganic and organic impurities that are present in wastewater in a dissolved form.

Suspended solids – an indicator of the amount of impurities in the first group that remain on the filter after filtration and drying to a constant mass. This indicator characterises the amount of sediment formed during wastewater treatment and is used in the design of sedimentation tanks.

Oxidisability. The oxidisability of wastewater characterises the total content of organic and inorganic reducing agents in water. In wastewater from processing plants, these are mainly organic substances. A distinction is made between permanganate and bichromate oxidisability of water. Permanganate oxidisability is determined using $KMnO_4$, which is a weak oxidising agent, while dichromate oxidisability is determined using $K_2Cr_2O_7$, which is a much stronger oxidising agent than the former. Bichromate oxidisability is abbreviated as COD (chemical oxygen demand), permanganate oxidisability – BOC (biochemical oxygen demand). Both indicators have the dimension mgO_2/dm^3. The COD indicator is the oxygen equivalent of the amount of organic substances in wastewater impurities. The BOC indicator determines the amount of oxygen required for the vital activity of microorganisms involved in the oxidation and destruction of organic substances present in wastewater impurities.

Nitrogen, phosphorus. Nitrogen is present in wastewater in the form of organic and inorganic compounds, primarily in the form of fish proteins and their decomposition products. Inorganic nitrogen compounds are represented by reduced forms of nitrogen NH_4^+ and NH_3, as well as oxidised forms NO_2^- and NO_3^-. Reduced forms are dissolved in water and are in dynamic equilibrium according to the equation:

$$NH_3 + H_2O \leftrightarrow NH_4^+ + OH^-$$

In the wastewater of fish processing enterprises, before treatment, nitrogen in oxidised forms (nitrites and nitrates) is practically absent and appears only after biological treatment, which indicates the complete completion of the process.

The source of phosphorus in wastewater is fish raw materials. The nitrogen and phosphorus content in wastewater characterises the quality of the biological treatment process. These elements are called biogenic elements. In the absence of nitrogen, carbon and phosphorus in water, biological treatment of wastewater is impossible.

Chlorides and sulphates are impurities that do not significantly affect the rate and efficiency of wastewater treatment if their concentration is low.

For example, in the wastewater of fish processing enterprises, the content of table salt is quite high (up to 1000–1400 mg/dm^3), in order to avoid salinisation of water bodies receiving wastewater, it is necessary to prevent the discharge of

highly mineralised wastewater into urban drainage systems, especially when discharging wastewater into open water bodies.

The concentration of sulphates can only change under anaerobic conditions during treatment in sedimentation tanks and fermentation of sludge in methane tanks. In this case, sulphates are reduced to sulphides and, at concentrations above 1 g/dm^3, can disrupt the methane fermentation process.

Surfactants. Synthetic surfactants (SPAR) enter wastewater during the washing of technological equipment. These compounds impair the sedimentation process of suspended particles, forming a large amount of foam in aerated treatment facilities and inhibiting biochemical processes in biooxidizers.

Oil-soluble substances include fats (such as fish oil) and vegetable oils. They pose a major obstacle to wastewater treatment. As their removal is so difficult, it is necessary to limit the concentration of these substances in the raw wastewater; this can be achieved by implementing more advanced processing of raw materials and the recycling of fatty waste.

Dissolved oxygen. There is no dissolved oxygen in the wastewater entering the treatment plant. Wastewater treated by biochemical means must contain at least 2 mg/dm^3 of dissolved oxygen, which is added by force. In wastewater discharged into reservoirs for domestic and cultural water use, the dissolved oxygen content must not be less than 4 mg/dm^3, and in reservoirs for fish farming, it must not be less than 6 mg/dm^3.

Sanitary and bacteriological indicator. These indicators are determined by the total number of aerobic and facultative anaerobic saprophytic microorganisms (microbial count) and bacteria of the intestinal stick group (BISG).

The microbial count determines the contamination of wastewater with microorganisms and indirectly characterises the pollution of water with organic substances – sources of nutrition for saprophytic microorganisms.

This indicator in the wastewater of fish processing enterprises is 10^6 – 10^8 microbial cells per 1 cm^3.

The degree of contamination of water with pathogenic microorganisms is indirectly assessed by the number of BGKP in the water – representatives of the *Enterobacteiaceae* family, belonging to the genera *Escherichia, Citrobacter, Enterobacter, Klebsiella*. The genus *Escherichia* – mainly the species E.coli – has the greatest sanitary significance.

Depending on the objectives of laboratory studies, a necessary set of indicators is selected. To assess wastewater contamination, the values of suspended solids, ether-soluble substances and **BOC** are determined. Wastewater is considered slightly polluted if the suspended solids and **BOC** are up to 100 mg/dm^3, moderately polluted if they are between 100 and 500 mg/dm^3, and heavily polluted if they exceed 500 mg/dm^3.

In terms of ether-soluble substances, wastewater is considered to be slightly polluted if its content is up to 25 mg/dm^3, moderately polluted – 75 mg/dm^3, and concentrated – over 75 mg/dm^3.

The ratio of easily oxidisable and difficult-to-oxidise compounds can be determined by analysing the degree of oxidisability. Thus, the difference between

the results of oxidizability determinations by COD and **BOC** can establish the proportion of hard-to-oxidise organic substances in wastewater. The ratio of **BOC** $_{(total)}$ to COD characterises the degree of wastewater impurities' ability to undergo biological oxidation. For untreated wastewater from processing plants, this value is 0.72, and after treatment, it is 0.68. Determining the **BOC**, ammonium nitrogen and phosphate content allows us to assess the adequacy of biogenic elements for successful biological wastewater treatment.

A complete analysis of wastewater is usually carried out once every 10 days. The composition of wastewater fluctuates greatly during the day, and to avoid errors, average or average proportional samples are taken. If the amount of water discharged is more or less constant, only an average sample can be taken, i.e. a sample composed of equal volumes of liquid taken at equal intervals. An average proportional sample is taken in the case of irregular discharge of wastewater in portions proportional to the volumes of water discharged and also taken at equal intervals. Both average and average proportional samples are usually taken during the day, pouring individual portions into large, clean bottles. At the end of the day, the contents of the bottles are mixed and a portion of the liquid (1–3 dm^3) is taken for analysis in clean, washed containers.

Proper sampling of wastewater is very important for assessing the technological process and the operation of treatment facilities, as well as for developing new treatment methods. The sampling location is selected taking into account the tasks at hand, local conditions, production technology, sewage system and treatment facilities.

To preserve the substances determined in the water and the properties of the water unchanged for some time, the samples are preserved, but only in cases where this does not interfere with the determination of the components present in the water. Samples for determining **BOC** cannot be preserved. Samples for determining all types of bound nitrogen and COD are preserved by adding sulphuric acid: 2 cm^3 of diluted (1:3) sulphuric acid is added to each dm^3 of the water being tested. Samples for determining suspended solids and dry residue are preserved by adding 2 cm^3 of chloroform per 1 dm^3 of test water. To determine phenols, the wastewater is alkalised by adding 5 g of caustic alkali per dm^3 of water. Samples containing less than 0.05 mg/dm^3 of phenols should be analysed immediately. The kinetics of precipitation of coarse impurities should be determined at the sampling site.

6.2. Composition and content of pollutants in wastewater from processing enterprises

The products manufactured by processing enterprises are highly diverse in terms of both the raw materials used (e.g., different types of fish and non-fish products) and in terms of assortment (canned, preserved, salted, dried, smoked, frozen fish products, culinary products, feed meal). Raw materials of varying degrees of freshness can be used in production. In addition, even when producing the same range of products, different technologies and different technological

equipment may be used. In addition to raw materials, various auxiliary materials are also used: cereals, vegetables, vegetable oils, spices, table salt, smoking preparations, antiseptics, antioxidants, stabilisers, etc.

During the production process, raw materials and auxiliary materials interact with water in such technological operations as washing raw materials and materials, hydrotransportation of fish and fish processing waste, defrosting, portioning fish, during brine salting, soaking and rinsing salted fish, and many others. In addition, the production of fish products requires maintaining a high level of sanitary conditions in production, therefore, technological equipment, containers, and inventory are thoroughly washed after use, resulting in an additional amount of contaminated water. Wastewater is converted into so-called *production wastewater.* As a result, the total wastewater contains various substances, primarily organic substances: blood, mucus, pieces of fish, scales, residues of cereals, flour, and vegetables. Protein substances enter the wastewater in a denatured, colloidal, dissolved state, as well as non-protein nitrogenous substances, enzymes, vitamins, fish fats, vegetable oils and products of their hydrolysis and oxidation, etc. Mineral substances entering wastewater include sand, shell rock, table salt, as well as calcium and magnesium salts, etc.

For example, wastewater from fish processing plants is cloudy, brownish-grey in colour, has an unpleasant odour and high microbial contamination, reaching 10^8 or more microbial cells per 1 cm^3.

6.3. Conditions for discharging wastewater into a water body

The conditions for discharging wastewater into a water body are determined by its economic significance and the nature of water use. They are regulated by the «Rules for the Protection of Surface Waters from Pollution» and the «Rules for the Sanitary Protection of Coastal Waters».

After the discharge of wastewater, some deterioration in the quality of water in water bodies is permissible. However, this should not affect the life of the water body and the possibility of its further use for its intended purpose – as a source of water supply, for cultural and sporting events, for fisheries purposes.

The conditions of discharge are controlled by sanitary and epidemiological stations, basin water protection authorities, fisheries water protection authorities, and fisheries organisations. The classification of a water body for one type of water use or another is carried out by the State Sanitary Supervision Authorities (Fig. 6.1).

The discharge of wastewater containing radioactive substances into the domestic sewage system is regulated by the Sanitary Rules for the Handling of Radioactive Substances and Sources of Ionising Radiation (Table 6.1).



Fig. 6.1. Discharge of wastewater into a reservoir [50]

The conditions for discharging wastewater into water bodies in accordance with the Rules apply to water bodies, regardless of their departmental affiliation, subject to mandatory approval by the state sanitary supervision and fisheries protection authorities.

Table 6.1. Indicators of impurities in water bodies after wastewater discharge

<table>
<tr><td rowspan="3">Indicators</td><td colspan="2">Water body areas</td><td colspan="2">Water body areas used for fishery purposes</td></tr>
<tr><td>for domestic and drinking purposes</td><td>Cultural and domestic purposes</td><td>for the reproduction and conservation of valuable fish species</td><td>for all other fisheries purposes</td></tr>
<tr><td colspan="4">An increase of no more than</td></tr>
<tr><td rowspan="2">Content of suspended substances, mg/dm^3</td><td>0.25</td><td>0.75</td><td>0.25</td><td>0.75</td></tr>
<tr><td colspan="4">For water bodies containing more than 30 mg/dm^3 of natural mineral substances, an increase in content of 5% is permitted.
Wastewater containing suspended solids with a sedimentation rate of more than 0.4 mm/s for flowing water bodies and 0.2 mm/s for reservoirs is prohibited from being discharged.</td></tr>
<tr><td>Film of petroleum products, oils, fats and other floating impurities</td><td colspan="4">Not permitted</td></tr>
<tr><td rowspan="3">Odours and tastes</td><td colspan="2">Water must not acquire odours and tastes with an intensity greater than</td><td colspan="2" rowspan="3">Water must not have odours or tastes of meat or fish</td></tr>
<tr><td>2 points</td><td>3 points</td></tr>
<tr><td colspan="2">Immediately or after chlorination</td></tr>
<tr><td rowspan="2">Colour</td><td colspan="2">Colouration should not be visible in the water column</td><td colspan="2" rowspan="2">Colouration of water affecting fish meat is not permitted</td></tr>
<tr><td>20 cm</td><td>10 cm</td></tr>
<tr><td>Water temperature</td><td colspan="2">The water temperature may be increased by no more than 3 ^{0}°C compared to the average monthly temperature of the hottest month in the last 10 years</td><td colspan="2">The water temperature may be increased by no more than 3 ^{0}°C in summer and 5 ^{0}°C in winter.
For cold-loving fish, the water temperature should not exceed 20 ^{0}°C in</td></tr>
</table>

			summer and 5 ^{0}°C in winter, and for other species, 28 and 8 ^{0}°C, respectively.	
pH	6.5 – 8.5		6.5 – 8.5	
Salt content of water	Should not exceed 1000 mg/dm^3, including		Not regulated	
	Chlorides – 300 mg/dm^3, sulphates – 100 mg/dm^3	No taste		
Dissolved oxygen, mgO_2 /dm^3	Not less than 4.0 at any time of the year in a sample taken before 12 noon		Not less than 6 in summer and not less than 4 in winter	Not less than 6
BOC $_{total}$ at a temperature of 20 ^{0} C	Must not exceed			
	3	6	3	
Pathogens	Not permitted (after disinfection of biologically purified water, the coli index must not exceed 1000, residual chlorine content 2.5 mg/dm^3)			
Toxic substances	Not permitted in concentrations that may have a direct or indirect impact on living organisms			

In order to protect coastal waters used for domestic and drinking water supply, technological purposes, medical, resort and health needs from pollution, local or state authorities establish two sanitary protection zones:

- the first sanitary protection zone is designed to prevent microbial and domestic pollution of water in excess of the established standards within the limits of water use. To organise discharges, the boundaries of this zone must be located at a distance of 2 to 7 miles from the nearest shore;
- the second sanitary protection zone is designed to prevent contamination of water in the water use area and the first sanitary protection zone from the sea by marine vessels and industrial facilities involved in oil and gas extraction. The boundary of this zone shall be located at a distance of 7 to 12 nautical miles from the nearest shore.

Depending on the specific hydrophysical and hydrological characteristics of the sea coast, the width of the water use area towards the sea may be increased or decreased in agreement with the sanitary and epidemiological services and averages 2 miles.

All territorial waters that can be used for industrial fishing and other aquatic animals and plants or are important for the reproduction of industrial fish stocks are considered fisheries.

The coastal water use protection zone is considered to be a two-mile coastal strip of land.

Within the coastal areas of water use, it is prohibited to discharge treated wastewater, both industrial and domestic, with the exception of disinfected seawater from basins. Within the first belt of the sanitary protection zone, only biologically treated and disinfected water may be discharged.

It is prohibited to establish landfills, store pesticides, mineral fertilisers and other harmful substances on the seashore.

Fishing enterprises shall submit reports to the Central Statistical Office and local water protection authorities in the prescribed form on water use and the conditions of wastewater discharge and the degree of pollution.

6.4. Protection of coastal waters from pollution from ships

To prevent pollution of territorial waters from ships passing through and entering ports, ship captains must comply with the following basic rules:

- the design and equipment must comply with the requirements established by international treaties on the prevention of marine pollution from ships;
- harmful substances prohibited from being discharged into inland seas and territorial waters must be collected on board the ship in special containers and then delivered to shore or floating reception facilities or disposed of on board the ship;
- operations with harmful substances or mixtures thereof carried out on ships are subject to mandatory registration in the ship's documents;
- operations involving the reception and delivery of harmful substances and mixtures thereof shall be recorded on collection vessels;
- on floating treatment facilities, operations involving the reception from ships and treatment of wastewater contaminated with harmful substances shall also be recorded;
- any loss or accidental discharge of harmful substances or mixtures thereof from ships into coastal waters must be reported to the nearest port authority as soon as possible;
- the treatment of spilled oil or other harmful substances with chemical agents is prohibited, as this must be carried out by specialised services;
- only cleaning agents approved by the sanitary and fisheries authorities may be used for cleaning decks, tanks and other areas;
- to protect coastal waters from discharges from ships at anchor, ports must be equipped with devices that allow domestic waste to be discharged into the municipal sewage system;
- Maritime, commercial and fishing ports where ships are moored must have facilities for receiving waste from ships and its subsequent disposal and neutralisation.
- Vessels entering ports must have a declaration of commitment to comply with port requirements.

According to the requirements of the Register's rules, the discharge of wastewater in the water use area is prohibited. After treatment, wastewater may be discharged in permitted areas with the following indicators:

- suspended solids – 50 mg/dm^3;
- BOC_5 – 50 mgO_2 /dm^3;
- coli index – 1000;
- free chlorine content – 0.3 – 0.5 mg/dm^3.

A fish processing vessel located outside territorial waters more than 50 miles from the coast may discharge wastewater in the wake of the vessel at a speed of not less than 4 knots at 30 dm^3 per knot for no more than one hour.

6.5. Determination of the required wastewater treatment efficiency

The efficiency of wastewater treatment for certain pollutants is determined by the formula:

$$E_{oc} = (C_{start} - C_{end})\ 100/C_{start},$$

where E_{pur} – purification efficiency, %;

C_{in} and C_{out} – pollutant content in wastewater before and after treatment, respectively.

If the maximum permissible concentrations (MPC) of pollutants for wastewater discharge from an enterprise are known, it is always possible to determine the efficiency with which they must be treated. In this case, the pollutant for which the highest treatment efficiency is required is taken for calculation. This pollutant indicator is determined as the limiting MPC of pollutants in wastewater before discharge into the sewerage system.

For example, if wastewater from a fish processing plant is discharged directly into a water body, the MPCs for these substances are set by the sanitary and epidemiological station in conjunction with the water protection authorities and approved by the local authorities, and sometimes by higher-level authorities for each fish processing plant separately, taking into account the hydrological and hydrochemical regime of the specific section of the water body (Table 6.2).

Table 6.2. Requirements for the composition of wastewater from fish processing plants discharged into water bodies

Indicator	Value
Odour	No more than 2 points
Colour	Absent
pH	6.5 – 8.0
BOC_p	45 – 120 mgO_2 /dm^3
COD	60 – 142 mgO_2 /dm^3
Suspended solids	80 – 85 mg/dm^3
Ether-soluble substances	15 – 96 mg/dm^3
Protein	25–96 mg/dm^3
Residual chlorine	15 mg/dm^3
Coli index	no more than 1000
Viable helminth eggs	Absent
Toxic substances	none

To treat wastewater from processing enterprises to the required level, the following devices may be included in the composition of the plant's treatment facilities: screens, sand traps, grease traps, sieves, flotation units, electroflotation units, electroflotation coagulators, and reagent treatment devices.

For additional purification after mechanical and physicochemical treatment of wastewater, ultrafiltration, sorption, ultrasonic treatment and other methods can be used.

Before being discharged into the sewer or water body, wastewater must be disinfected by chlorination or ozonation.

Questions for discussion and self-assessment

1. What are water consumption and water disposal standards, and in what units are they measured?
2. In what cases is it permissible to use a direct-flow water consumption system?
3. In which technological processes is it advisable to treat wastewater before mixing it with general effluents?
4. What formula can be used to calculate the required volume of water to feed the system when organising a recirculating water consumption system?
5. What formula characterises the efficiency of a water consumption system at an enterprise?
6. How can water losses be determined as a percentage?
7. How to determine the wastewater flow rate in any technological process by volume?
8. How is the wastewater flow rate determined by water discharge through a rectangular overflow?
9. How is the flow rate of wastewater containing an increased amount of suspended solids determined using a transverse partition?
10. How is wastewater discharge calculated based on pump operation? 14. How to determine the daily wastewater discharge and the coefficient of unevenness of its removal?
11. What is the significance of the unevenness coefficient for wastewater from fish processing plants?
12. What pollution indicators are characteristic of wastewater from fish processing plants?
13. Why are there temperature restrictions for wastewater to be discharged?
14. How does temperature affect the wastewater treatment process?
15. Colour and odour are cumulative indicators of impurities contained in wastewater. How are they determined in practice?
16. How are suspended solids, dry, incinerated and dense residues determined in wastewater?
17. What characterises permanganate and dichromate oxidisability of wastewater? What is their dimension?
18. In what form are nitrogenous substances found in the wastewater of fish processing enterprises?
19. What are the sources of nitrogen and phosphorus in wastewater?

20. What are the sources and levels of chloride in wastewater from fish processing plants?
21. What methods can be used to prevent the discharge of concentrated effluents into the sewerage system?
22. What are the sources of ether-soluble substances in wastewater from fish processing plants?
23. What indicators characterise the sanitary and bacteriological condition of wastewater?
24. What groups are wastewater divided into according to the degree of contamination with suspended and ether-soluble substances?
25. What is the procedure for sampling wastewater to determine the composition of impurities in it?

CHAPTER 7. WASTEWATER TREATMENT METHODS

Wastewater from processing plants is treated using mechanical, physical-chemical and biological methods. Based on data on wastewater flow rates, their detailed characteristics, in particular their impurity content, knowledge of the requirements for treated water and taking into account technical and economic indicators, the most optimal method of wastewater treatment is selected. Disinfection is used to neutralise bacterial contamination of wastewater. Wastewater treatment should ensure minimal discharge of wastewater into water bodies, maximum use of treated wastewater in technological processes and recirculating water supply systems, and more complete removal of valuable impurities.

Three main types of treatment facilities are used for wastewater treatment: local (workshop), general (factory) and municipal. Local and factory treatment facilities are used at processing enterprises.

Local treatment facilities are designed to treat wastewater directly after processing equipment and are an extension of the production process. Local facilities treat wastewater that cannot be sent to reuse and recycled water systems without treatment. At these plants, impurities are usually extracted from wastewater, some of which may have feed or technical value. Regenerative treatment methods are used: filtration, settling, flotation, adsorption, ultrafiltration and others.

Factory treatment facilities are designed to treat general wastewater from the enterprise to a level that allows it to be discharged into the municipal sewerage system or a reservoir. Factory treatment facilities include mechanical, physical-chemical and sometimes biological treatment of general wastewater from the enterprise.

Mechanical treatment facilities include screens, sand traps, sedimentation tanks, etc. Physical and chemical treatment of wastewater is carried out using flotation, electroflotation, and electrocoagulation units, by reagent treatment followed by sedimentation or flotation. Biological treatment facilities designed for the biological destruction of organic substances include biological filters, aerotanks, biological ponds, etc. Chlorination, ozonation, and UV irradiation of treated wastewater are used for disinfection.

Wastewater inflow and characteristics

The technological analysis of the treatment plant's operation begins with determining the quantity and quality of wastewater.

Wastewater usually enters the plant unevenly, which is assessed by daily, hourly and total unevenness coefficients. Since the technological indicators of the operation of individual structures (residence time, aeration period, etc.) are calculated based on the average daily inflow, the unevenness of the wastewater inflow should be taken into account during the analysis. The concentration of pollutants in wastewater varies even more: in summer, the concentration is usually

lower than in winter. Sometimes there is an increase in the concentration of pollutants in summer, which is associated with the shutdown of the city's hot water supply system for repairs. Usually, the concentration of pollutants decreases sharply on Sundays and public holidays when industrial enterprises are not operating.

A comparison of the results of analyses on weekdays and public holidays gives an idea of the composition of domestic wastewater and the impact of industrial effluents on its composition. Analysis of hourly wastewater samples shows that the concentration of pollutants varies throughout the day (with a suspended solids content of 200 mg/l in a 24-hour sample, their content in hourly samples varies from 50 to 350 mg/l).

The evaluation of the results of analyses of incoming wastewater and treated wastewater, the comparison of wastewater inflow with the calculated capacity of the station, the results of analyses with design data and those determined for the same period last year, makes it possible to evaluate the operation of the station as a whole and its individual structures. The diagram below shows the wastewater treatment process at the Bortnytska aeration plant:

screening unit ➜ grit chamber (➜ sandpits) ➜ primary clarifier ➜ aeration tank ➜ secondary clarifier ➜ activated sludge ➜ sludge treatment plant ➜ sludge fields
primary settling tank ➜ anaerobic digesters

7.1 Mechanical treatment of industrial wastewater

Mechanical treatment is used to remove insoluble mineral and organic compounds (impurities) from wastewater in order to prepare it for physical-chemical, biological and other methods of more thorough treatment. Mechanical treatment includes:

- screening through grates (removal of large contaminants – rags, scrubbing brushes, paper, pieces of wood, fish);
- sand traps (removal of mineral contaminants – sand, clay, small gravel, shell fragments);
- settling (removal of organic insoluble contaminants – small pieces of fish, auxiliary materials);
- filtration (removal of organic debris).

Mechanical cleaning ensures the removal of 90–95% of suspended solids of mechanical origin and 25–50% of suspended solids of organic origin, with a total reduction in organic pollution of 20–25%. A high cleaning effect is achieved by settling in a thin layer (thin-layer sedimentation tanks) and with the help of hydrocyclones. More complete clarification is achieved by filtration through a layer of various materials (quartz, sand, gravel, expanded clay, slag) or through mesh drum filters, floating load filters, etc.

The choice of method for purifying wastewater from suspended solids is made taking into account the kinetics of the process. If the particles are large

enough (30 – 50 μm), they can be separated by settling according to Stokes' law (at high concentrations) and by filtration through microfilters (at low concentrations). For particles up to 10 μm in size, the final settling velocity is less than 10 cm/s. Such particles, as well as colloidal particles (0.1–1.0 μm in diameter), can be removed by filtration. However, due to the limited capacity of the filter layer, a more suitable method for concentrations of suspended particles above 50 mg/dm³ is coagulation followed by settling.

In order to ensure the reliable operation of mechanical treatment facilities for industrial wastewater, it is recommended to use at least two operating units of the main technological purpose – screens, sand traps, equalizers, sedimentation tanks or filters.

Improving the effectiveness of mechanical wastewater treatment makes it possible to reduce the size of facilities for subsequent treatment processes and thus reduce the cost of construction and operation of more expensive and complex facilities for physical-chemical and biological treatment, as well as sludge treatment.

7.1.1 Screens (Grates)

Raking section (screens). A technological analysis of the operation of screens in terms of the quantity and quality of waste is more indicative of the composition of the incoming wastewater than the operating mode of the facility, which is mainly determined by the flow rate of water through the screen. The amount of waste retained by the screens can vary greatly, from 10 to 80 litres per 1,000 m³ of wastewater. The amount of waste removed from the screens depends not only on the composition of the wastewater, but also on the method of delivery – by gravity or by pumping stations equipped with coarse screens that retain large waste. If pumping sludge from sand traps is difficult due to clogging of the hydroelevators, it is necessary to check the size of the openings (distance between the bars) of the screens: at 20 mm and above, less waste is retained than at 16 mm. The speed of wastewater in the gaps is regulated by the number of grates in operation and should not exceed 1 m/s at maximum wastewater inflow. The quality of waste is characterised by moisture content, ash content and composition, which vary significantly: moisture content from 40 to 85%, ash content from 2 to 40 %, textile content – 24 – 80 %, paper content – 12 – 60%, other content – 4 – 40% (Fig. 7.1).

Grates are used to clean wastewater from large impurities, which, if they enter the treatment plant equipment, could cause operational difficulties or breakdowns. Grates are located directly in the production workshops, as well as on the main channel through which wastewater enters the plant's treatment facilities. The main structural element of grates is a series of rods of various shapes, placed horizontally in rooms in a recess in the floor and inclined or vertically across the channel. Depending on the distance between the bars, grates are classified as dense (with a clearance of 10 – 20 mm), medium (20 – 40 mm) and sparse (over 40 mm).

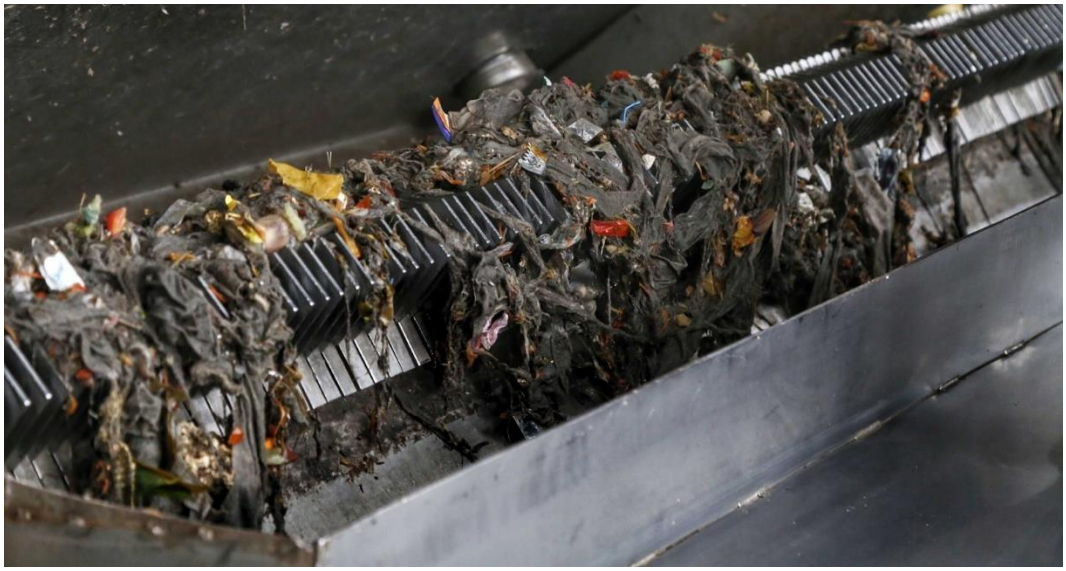


Fig. 7.1. Raking section (screens) [6]

When choosing grates, the size of the mechanical impurities to be removed is of decisive importance. For example, wastewater directed to a settling tank with mechanical sediment removal must pass through grates with a distance between bars of 20 mm. Gratings with more sparse bars can be installed indoors. Gratings are cleaned manually or mechanically (the latter are installed at large treatment plants).

The grate is installed at treatment facilities in the event of gravity flow of wastewater. In the case of wastewater supply by pumps with grates installed in front of them with openings of 16 mm and less, it is permissible not to use grates at treatment facilities.

In the food industry (including the fish industry), special screens with manual removal of impurities are most often used. They retain very large impurities (tin cans, pieces of wood, rags, paper, raw materials being processed, and auxiliary materials) (Fig. 7.2).

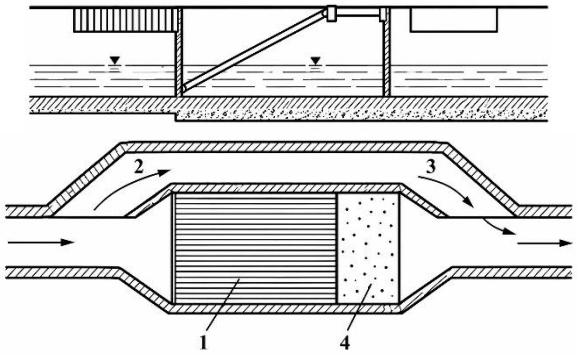


Fig. 7.2. Stationary screen with manual cleaning

1 – coarse screen; 2 – fine screen; 3 – bypass channel; 4 – collection area for captured impurities

Given the need for periodic cleaning of the grate and the uneven flow of wastewater, an overflow equipped with grates with a smaller opening is installed

in the channel in front of the grate to divert part of the wastewater past the main grate. Impurities should be removed at least once per shift. They are sorted, waste raw materials and auxiliary materials are selected, which are crushed, preserved, and then sent either to feed livestock or for industrial processing in a fish meal plant. The rest of the waste is taken to a landfill.

7.1.2. Sieves

Sieves are used to remove small suspended solids (larger than 1 mm). The main element of the sieve is a woven mesh or perforated iron through which wastewater is filtered. The size and shape of the holes in the mesh depends on the type and nature of the impurities. Sieves are classified as stationary or mobile depending on their design.

Stationary screens

In stationary screens, the filter element is fixed in place, and suspended solids are removed continuously by means of rakes (Fig. 7.3).

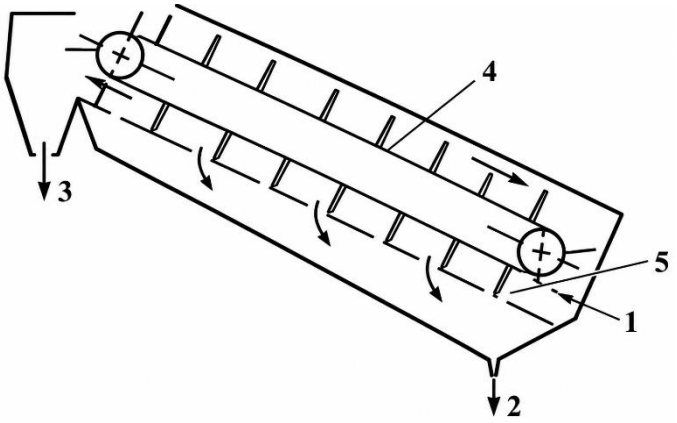


Fig. 7.3. Schematic diagram of a stationary screen

1 – inlet for water containing impurities; 2 – outlet for filtered water; 3 – impurities; 4 – scraper conveyor for collecting impurities; 5 – screen.

Wastewater is fed to screen 5, filtered through it, collected in a receiving tank and discharged via pipeline 2. Impurities remaining on the screen are collected in a hopper by means of scraper conveyor 4 and discharged via pipe 3. These devices use woven mesh or perforated sheet screens. Woven screens are made from wire with a trapezoidal cross-section. The mesh size is 1.0–1.5 mm. On the effluent outlet side, the mesh diameter is approximately 0.2 mm larger. In the fishing industry, screens made of perforated steel sheet, curved into a parabolic shape, are also used. Water is fed onto it from the outside, and contaminants are removed by gravity into a receiver.

Moving screens

These include rotating screens-disc, drum, and vibrating screens.

Disc screens. A disc screen (Fig. 7.4) is equipped with a rotating disc 1, installed at an angle of 10–25° to the horizontal, ensuring that part of the screen surface (at least 25%) is always submerged in the wastewater.

Contaminants are removed from the disc screen using brushes 2 and discharged via a screw conveyor 3.

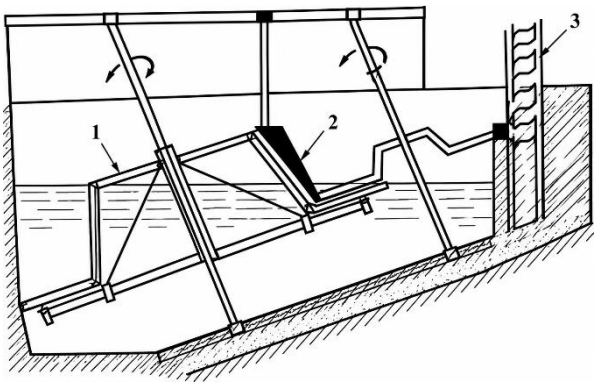


Fig. 7.4. Disc screen

1 – screen; 2 – brushes; 3 – screw conveyor

Drum screens. The main element of drum screens is a rotating cylinder with a stretched mesh. The filtering surface can be either the inner or outer surface of the drum. Examples of screens with an inner filtering surface include the Rolf screen and the Bobrovsky screen.

The Rolfov screen (Fig. 7.5) consists of a vertical rotating drum with a stretched mesh 4 and a collection tank for treated wastewater 5. The drum is mounted at an angle relative to the collection tank. Wastewater fed through distribution chute I from the internal filtration chamber into the drum enters the moving screen and, after filtration, flows into the collection tank 5. Particles retained on the screen are transported to the outlet 3 by the rotation of the drum. The screen is continuously cleaned by spraying water onto it from the outside.

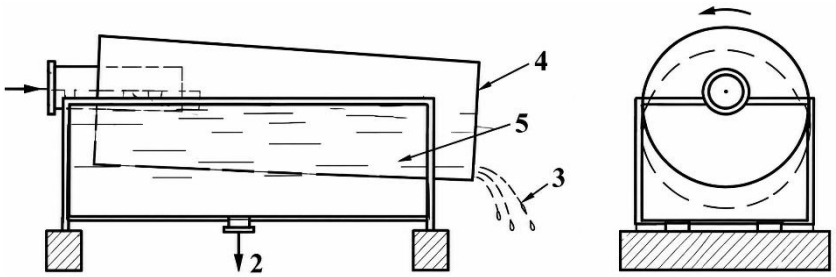


Fig. 7.5. Rolfov screen

1 – wastewater inlet; 2 – wastewater outlet; 3 – impurity outlet; 4 – rotating drum; 5 – collection tank

In Bobrovsky's screen (Fig. 7.6), suspended solids are retained on the outer side of the drum screen 4, which is half submerged in the collection tank 3 through which the wastewater flows. The wastewater filling the collection tank passes through the screen into the drum, from where it flows out through the hollow shaft 2, while the solid impurities retained on the screen are discharged by a moving brush into the second part of the collection tank, from where they are removed by a scraper conveyor 5.

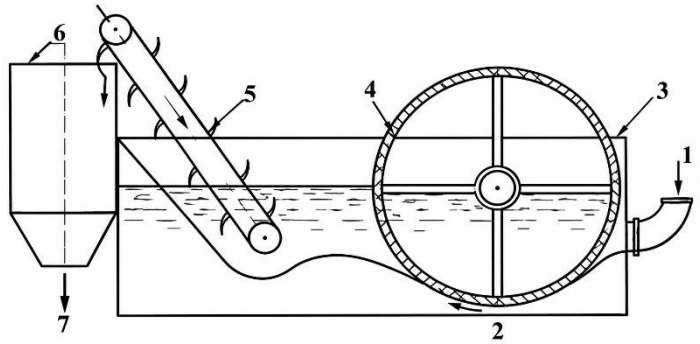


Fig. 7.6. Bobrovsky Screen

1 – wastewater inlet; 2 – wastewater outlet; 3 – collection tank; 4 – drum covered with mesh; 5 – scraper conveyor; 6 – hopper for collecting impurities; 7 – removal of impurities

Vibrating screens. The operating principle of vibrating screens is based on the combination of rapid screen vibrations with a small amplitude (1–3 mm) and a high frequency, corresponding to the rotational speed of the electric motor (1,450 or 2,900 rpm). A vibrating screen (Fig. 7.7) consists of a collection hopper 7 and a vibrating frame 3, over which a mesh 4 is stretched.

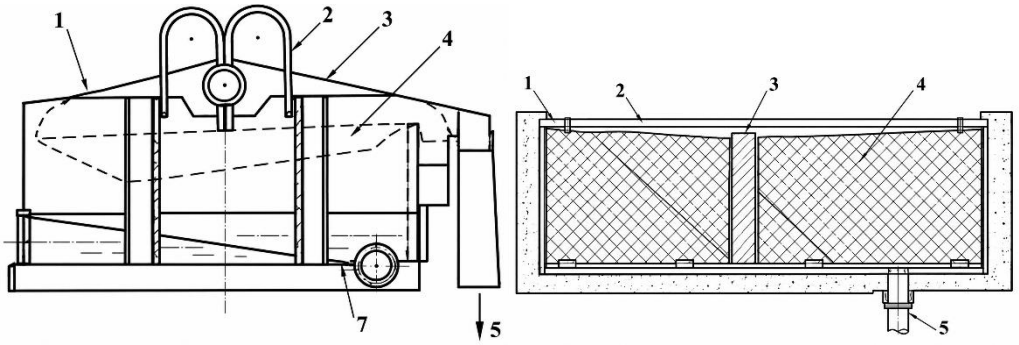


Fig. 7.7. Vibrating screen:

1 – wastewater inlet; 2 – spring; 3 – frame; 5 – impurity outlet; 6 – treated wastewater outlet; 7 – collection tank

The frame is mounted on a shaft supported by two flat steel springs 2. Eccentric discs are mounted on the shaft; as the shaft rotates, these discs impart rapid vibrations to the screen. After screening, the wastewater flows into the collection tank 7, while the retained solid impurities are transported by vibration to the discharge hopper 5.

Screens are typically installed in production facilities to remove raw materials and improve the composition of wastewater. It is important to select the appropriate screens based on their durability and the specific requirements of the process. The wastewater flow must be uniform, and retained particles must be systematically removed.

7.1.3. Sand traps

The performance of sand traps is evaluated by quantity and quality (average density, ash content, sand content and fractional composition), which vary widely.

As the flow rate decreases, sand traps retain a large amount of organic matter, which changes the quality of the sediment: the density decreases (to 1.2 – 1.4 g/cm^3), ash content (to 50 – 70 %), and sand content (to 35 – 60 %) (Fig. 7.8).

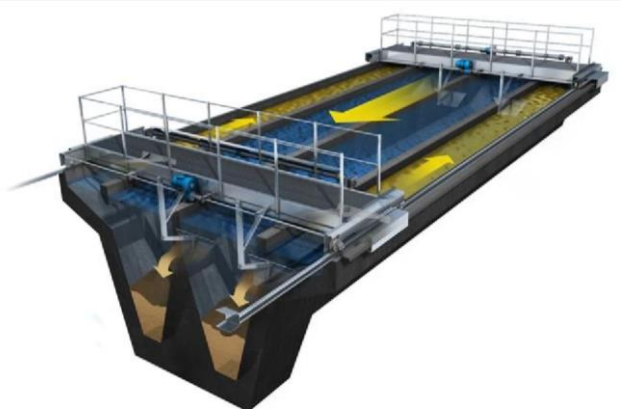


Fig. 7.8. Sand traps [6]

However, the improvement in the quality of the sediment retained by sand traps: an increase in density (to 1.5 – 1.8 g/cm^3), ash content (up to 80 – 95 %), sand content (up to 70 – 90 %) – does not give reason to consider the operation of sand traps satisfactory, since these indicators change when the calculated flow rate is exceeded due to an increase in the inflow of wastewater or the shutdown of some of the sand traps. At the same time, not only organic substances are removed from the sand traps, but also a significant part of the sand, as can be judged by the increase in the ash content of the sediment discharged from the primary sedimentation tanks. If the sand content in the sludge from the primary clarifiers does not exceed 6% and most of the sand removed is of fine fraction (less than 0.25 mm), then the sand traps are working satisfactorily.

By selecting the flow rate, sand traps are designed so that only heavier inorganic suspended solids settle, while lighter organic solids enter the sedimentation tank together with the wastewater. They must be provided to retain mineral particles with a diameter of more than 0.2 – 0.25 mm for treatment facilities with a capacity of more than 100 m^3/day. The number of sand traps should be at least two. Sand traps are designed for maximum water flow and checked for minimum wastewater inflow.

The principle of operation of sand traps is based on the phenomenon of sedimentation – the spontaneous settling of suspension particles under the action

of gravity. The rate of sedimentation of suspended solids depends on the ratio of gravity and resistance forces that arise during the sedimentation of suspension particles. For granular suspended substances, the dependence of the sedimentation rate on this ratio is expressed by Stokes' formula:

$$u = gd^2 \times (p_1 - p_2)/(18\mu),$$

where **u –** is the sedimentation velocity of suspended substances, cm/s;
g – acceleration due to gravity (9.81 cm/s);
p_1 – particle density, g/cm^3;
ρ_2 – fluid density, g/cm^3;
μ – dynamic viscosity of the liquid, g s/cm.

There are tables (with experimentally obtained data) on the rate of sand sedimentation in standing water depending on the size of the sand grains and the temperature of the liquid.

Since sedimentation in sand traps occurs under flow conditions, it is necessary to establish the direction and velocity of the fluid flow. Theoretically, in order for suspended particles to settle to the bottom of the sand trap at the velocity of this particle, the following conditions must be met:

- for vertical upward movement, **u** > **v**;
- for horizontal movement, **u** = **vh/L**,

where **u** is the settling velocity of the particle in a stationary fluid, mm/s;
v is the fluid flow velocity, mm/s;
h is the height of the liquid layer in the sand trap, m;
L is the length of the sand trap, m.

Horizontal sand traps

The simplest design of this type of equipment is a sand trap with manual sediment removal. Most often, it is made in the form of two troughs that operate alternately. A drainage system 3 is located at the bottom of the sand trap, which allows the retained sand to be dewatered (Fig. 7.9).

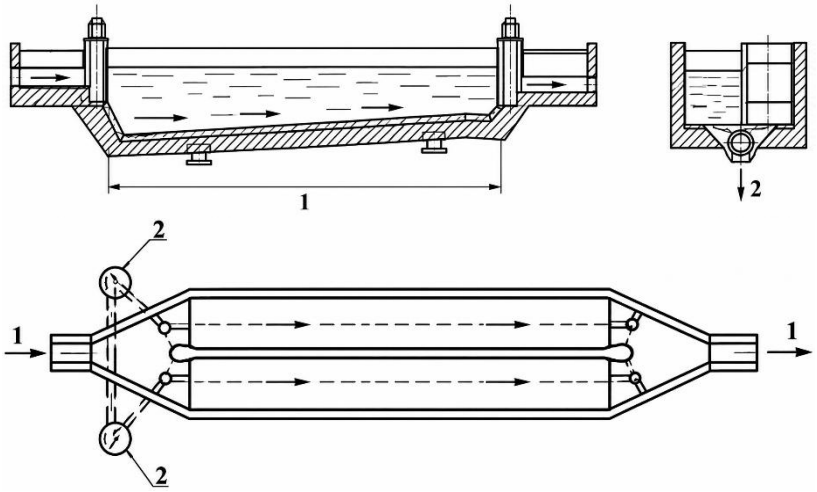


Fig. 7.9. Horizontal sand trap with manual sludge removal
1 – wastewater inlet; 2 – drainage wells; 3 – drainage

The sand is removed manually every 2 – 3 days. Such sand traps are used to treat wastewater with a low content of inorganic substances, which includes wastewater from the fishing industry. For high content of inorganic suspended solids, sand traps with mechanical raking of sediment into a settling chamber are used. The chamber is emptied of sand, most often continuously, using mechanical rakes (hydroelevators) or specially designed pumps.

Vertical sand traps

Vertical sand traps are manufactured in the form of round or polygonal cross-section collectors with a conical bottom or in the shape of a trapezoid. Their principle of operation is based on feeding wastewater in a narrow stream into the lower part of the device and then changing the direction of movement to vertical from below. At the same time, the speed of movement drops sharply and significantly. The diameter of the sand particles that settle depends on the vertical velocity of the wastewater. For example, at a flow velocity of 0.03 m, particles with a diameter of 0.25 mm settle.

Vertical sand traps have a low efficiency coefficient, but despite this, they are often installed in enterprises because they take up little space. The volume of the sedimentation part of the sand trap is taken to be equal to the daily amount of sediment (Fig. 7.10).

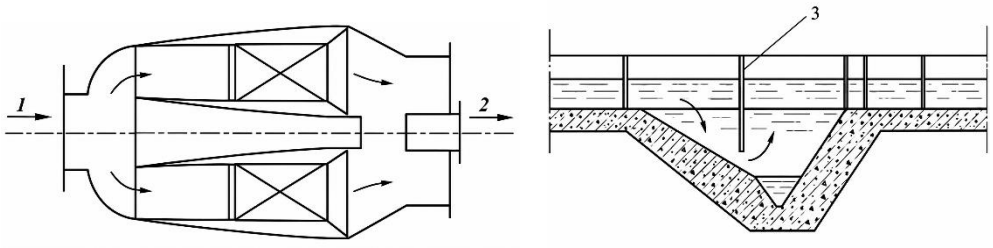


Fig. 7.10. Schematic diagram of a vertical sand trap
1 – wastewater inlet; 2 – wastewater outlet; 3 – crosswise partition

7.1.4. Settling tanks (primary)

Pre-aerators. The performance of pre-aerators is evaluated in conjunction with primary clarifiers in terms of the degree of suspended solids retention and BOC_5 reduction. The effectiveness of pre-aerators depends on the concentration of wastewater, the amount of activated sludge supplied, and the design of the primary clarifier. The effect of pre-aeration increases with increasing wastewater concentration.

The performance *of primary clarifiers* is evaluated based on the content of suspended solids and settleable solids in clarified water, as well as the moisture content of the discharged sludge (Fig. 7.11).

The station operates economically if the clarified water contains 55 – 80 mg/l of suspended solids and the sludge moisture content is 92 – 94 %. If the suspended solids content exceeds 100 mg/l, the operation of the aeration

station becomes uneconomical. In this case, the efficiency of the primary clarifiers is assessed by the amount of suspended solids retained and the reduction in BOC, which depend on the concentration of suspended solids in the wastewater and the residence time of the wastewater in the primary clarifiers.



Fig. 7.11. Primary sedimentation tanks [7]

If the wastewater residence time is 2 – 2.2 hours, 55 – 70 % of suspended solids are retained; if the time is reduced to 1.6 hours, the amount of retained suspended solids decreases to 40 – 45 %. The higher the concentration of suspended solids, the more of them are retained in the clarifiers, so the performance of the clarifiers can only be compared when the suspended solids content in the incoming wastewater is the same. The performance of structures located after primary sedimentation tanks is influenced not by the amount of retained substances, but by their concentration in clarified water. The higher the content of settleable substances, the better the primary sedimentation tanks should work. Their performance is influenced by temperature (they work better in summer than in winter), the amount of active sludge (if the sludge content exceeds 30 mg/l, the performance of the sedimentation tanks deteriorates) and the amount of sediment (if the sediment occupies part of the volume of the sedimentation zone, the sedimentation time of the wastewater is reduced and the sediment is washed out).

Settling tanks are the main element of every treatment plant. They are used:

- in a recirculating water supply system;
- for preliminary mechanical treatment of wastewater as primary settling tanks;
- for biological wastewater treatment using activated sludge as secondary settling tanks;
- in chemical wastewater treatment as coagulation sedimentation tanks.

The operating conditions of sedimentation tanks depend on the type of sediment (granular, flocculent), the desired degree of treatment and the nature of

the wastewater. In practical terms, this is expressed in the speed at which wastewater passes through the sedimentation tank, the duration of its stay in the tank, and the hydraulic load on its surface.

The speed of wastewater passing through the settling tank is 1 – 12 mm/s if the suspended solids are in flake form, and 1 – 50 mm/s if they are in granular form. The length of time the wastewater remains in the settling tanks varies from 10 – 20 minutes to two hours. A longer stay of wastewater in the settling tank is not recommended, as wastewater from the fishing industry quickly decomposes. In addition, increasing the duration of wastewater stay in the settling tank beyond 2 hours only slightly increases the effect of suspended solids removal, while significantly increasing the cost of constructing larger facilities.

Depending on the method of operation, settling tanks are divided into continuous (flow-through) and periodic action tanks. Flow-through settling tanks with horizontal wastewater flow are called horizontal tanks, and those with vertical flow are called vertical tanks.

The following data is required to calculate sedimentation tanks:

- the amount of wastewater at maximum inflow (Q, m^3/s);
- concentration of suspended heavy and light substances – protein substances, fat, mechanical impurities (C, mg/dm^3);
- the required degree of purification, or the permissible content of suspended substances in clarified water (C_{TR}, mg/dm^3), accepted in accordance with sanitary standards or determined by technical requirements;
- hydraulic particle size that must be separated to ensure the required purification efficiency E_{TR}, equal to 50–98%.

Hydraulic size **u**, which is determined by the settling kinetics curves $E = f(t)$ obtained in the laboratory under static conditions at a settling height $h_1 \geq 200$ mm or $h_2 \geq 400$ mm **($\Delta h = h_2 - h_1 \geq 200$ mm)**. To convert the obtained value to a layer equal to the height of the water flow layer in the settling tank, a recalculation is performed using the formula:

$$U = 100\,NK/[t_1(NK/h_1)^n],$$

where H is the depth of the flow part of the sedimentation tank, m;

K – coefficient of utilisation of the volume of the selected sedimentation tank design;

t_1 – duration of settling in a laboratory cylinder at a layer height h_1, during which the required purification effect is achieved;

K – proportionality coefficient. The coefficient K depends on the agglomeration of suspended substances during the sedimentation process and is determined by the formula:

$$n = (\lg t_1 - \lg t_2)/(\lg h_1 - \lg h_2)$$

where h_1 and h_2 are the heights of the settling layers in laboratory

conditions, mm;

t_1 and t_2 – duration of settling in the respective layers, at which the required settling effect is achieved, s.

If the temperature of the wastewater in production conditions differs from the temperature of the wastewater at which the settling kinetics are determined, a correction must be made:

$$u_0 = u \times \mu_l/\mu_n,$$

where $\mu_л$ and $\mu_п$ – are the viscosities of water at the corresponding temperatures in laboratory and production conditions;

u – hydraulic particle size obtained in the experiment.

Horizontal sedimentation tanks

Depending on the nature of the flowing liquid jets, which can be parallel or radial, horizontal clarifiers are divided into conventional (rectangular) and radial (circular).

Conventional clarifiers are used in factory treatment facilities to remove suspended solids from wastewater that has passed through screens and sand traps. During the treatment of wastewater from the fishing industry, horizontal clarifiers with continuous sludge removal are used. In such clarifiers, there is no additional water pollution due to decomposing organic sludge, as the sludge does not settle at the bottom of the clarifier but is removed immediately (Fig. 7.12).

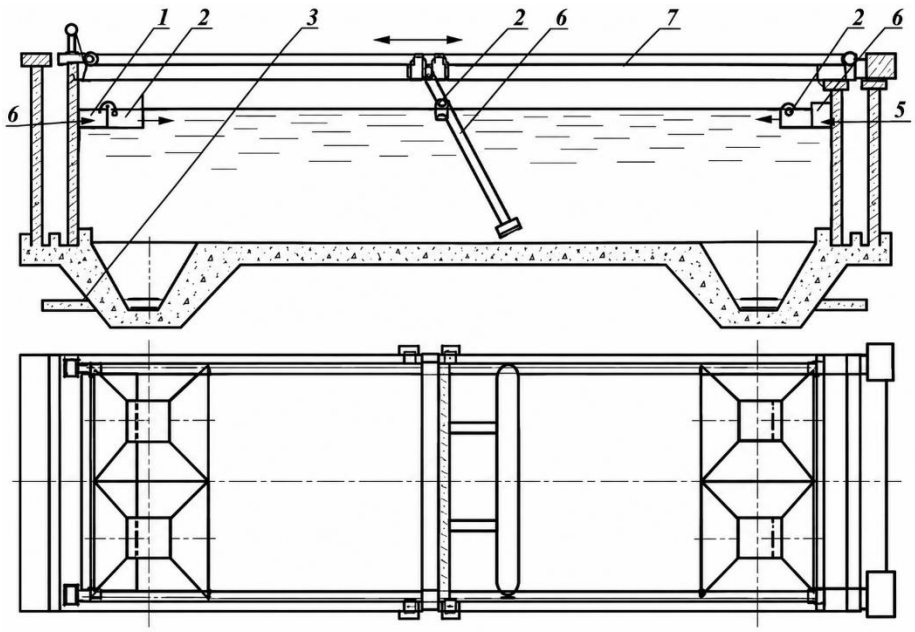


Fig. 7.12. Primary horizontal clarifier

A – wastewater inlet; B – wastewater outlet;

1 – distribution channel; 2 – inlet channel; 3 – sludge pipe; 4 – sludge sump; 5 – foam scraper; 6 – scraper mechanism; 7 – guide rope; 8 – foam collection trough; 9 – clarified water discharge trough; 10 – electric drive for the scraper mechanism

In the fishing industry, a system of three clarifiers is most often used: two operate in parallel, and the third is shut down for maintenance. Such clarifiers include a clarifier with mechanical sludge raking.

The mechanism for raking sediment 6 in horizontal clarifiers consists of a tubular beam mounted on two carriages that move directly along the concrete wall of the clarifier. A pendulum-type scraper is attached to the beam. The reciprocating motion of the mechanism is provided by a gear drive 10. The electric motor transmits torque via a gear transmission to friction drums, which move the mechanism along two guide ropes 7. Limit switches are installed at the extreme positions of the mechanism's travel; these are used to change the direction of the drive's rotation and the movement of the mechanism, which has a reversible stroke.

Technical specifications of the sedimentation tank with pendulum-type scrapers:

Dimensions of the sedimentation tank, m: length – 30; width – 9; depth – 3.8; speed of the scraper mechanism, m/min – 1.8. Electric drive power, kW – 0.6.

Radial clarifiers

Radial clarifiers are used for treating large volumes of wastewater. They can be installed in groups of four with a distribution basin for incoming wastewater. There are clarifiers with central and peripheral inlets for the wastewater to be treated. Most often, they are constructed as circular tanks with a diameter of 15 – 50 m and a depth of 1.5 – 5 m.

With a central inlet (Fig. 7.13), the clarifier consists of a cylindrical tank 6 with an annular channel for discharging clarified water. It is equipped with scrapers 3 that move the sludge from the periphery to the center.

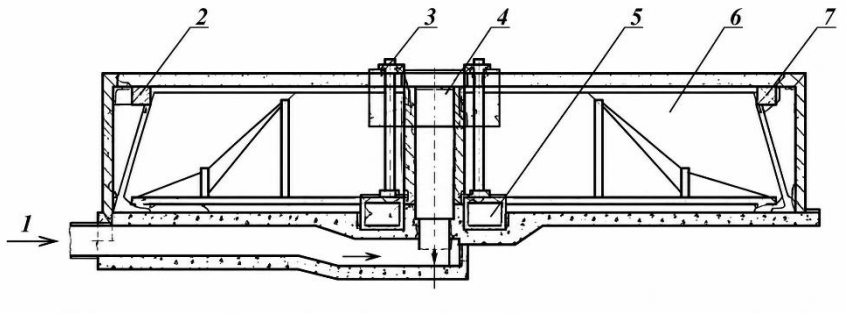


Fig. 7.13. Radial clarifier

1 – inlet pipe; 2 – peripheral channel for collecting clarified water; 3 – scraper mechanism; 4 – central inlet pipe; 5 – sludge collector; 6 – settling chamber

Wastewater enters the settling zone b at low velocity through pipe 4 and moves from the central part to the periphery, then flows out through the toothed peripheral trough 2 and exits the settling tank. Sludge from the bottom of the

clarifier is raked into the sludge chamber 5 using rotating scrapers 3, and from there is discharged by gravity or using pumps.

It has been established that rectangular clarifiers are superior to circular ones, especially if there are two or more of them and they share a common wall. In such clarifiers, sediment can be removed more quickly. They lack moving mechanisms located underwater. The land area required for rectangular clarifiers is smaller than for circular ones. The removal efficiency for suspended solids does not exceed 50%.

Vertical sedimentation tanks

Vertical clarifiers are used primarily to separate flocculent suspended solids from wastewater.

A vertical clarifier with a downward-flowing wastewater stream (Fig. 7.14) is a circular tank equipped with a peripheral trough for collecting clarified water 2.

Wastewater enters through the inlet trough 7 into the clarifier's water distribution trough 4, located on the inner side of a semi-submerged cylindrical partition 5, which divides the clarifier's volume into two equal parts. The depth of the partition's immersion is equal to ⅔ of the clarifier's working height. The water distribution trough has a serrated water outlet. As it moves from the partition toward the center, the wastewater descends, distributing across the entire cross-section of the clarifier's inner cylindrical section.

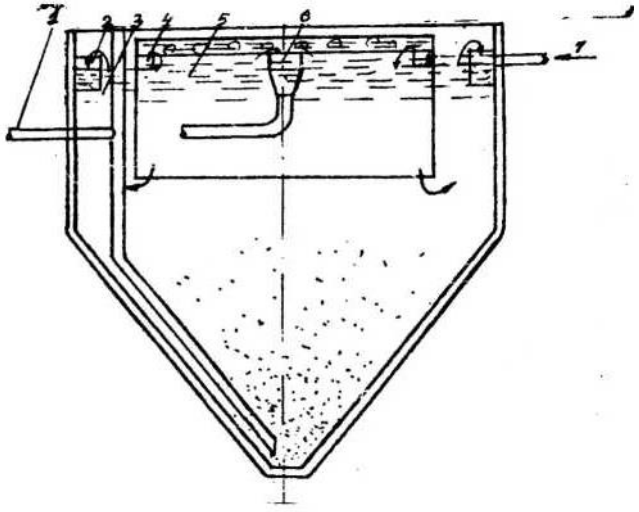


Fig. 7.14. Primary vertical clarifier

1 – sludge removal pipeline; 2 – peripheral channel for collecting clarified water; 3 – settling zone; 4 – inlet channel; 5 – annular semi-submerged partition; 6 – receiving funnel for removing floating impurities; 7 – pipeline for supplying wastewater

Floating solids are collected near the floating solids collection funnel 6 and periodically removed to a special sludge pit when the water level in the clarifier rises.

Intensive separation of the liquid and solid phases occurs at the flow bend in the lower part of the clarifier, where suspended solids also settle. Upon reaching the top of the clarifier, the clarified water flows through a serrated overflow into

the circular collection trough 2 and is discharged from the clarifier. The sludge is removed under hydrostatic pressure through the sludge pipe 1 into the sludge pit.

The clarifier ensures a significant reduction in the downward flow velocity, which promotes effective sedimentation of suspended solids. A clarifier of this type increases the retention rate of suspended solids to 60 – 70 % or, while maintaining the clarification efficiency of a conventional (horizontal) clarifier, increases the flow capacity by approximately 1.5 times.

Typical designs of vertical primary clarifiers have diameters of 4.5, 6.0, and 9.0 m; they are constructed of precast monolithic reinforced concrete, with flow capacities of 43, 87, and 196 m³/h.

7.1.5. Grease trap

Grease traps are used to remove contaminants in the form of fats and oils from wastewater, the density of which is lower than that of wastewater.

The principle of operation of these devices is based on the phenomenon of fat substances floating to the surface of the liquid. Since the floating process is similar to the sedimentation process, only the direction of movement of the separated particles is opposite, any collector in which the flow rate of wastewater is reduced can be used as a grease trap. The flow rate of the liquid should not exceed 6 mm/s, and the duration of wastewater settling should not exceed 1.5 – 2 hours.

The simplest design is a grease trap in the form of a rectangular flow collector, in which the supply and discharge of wastewater is carried out from below (Fig. 7.15).

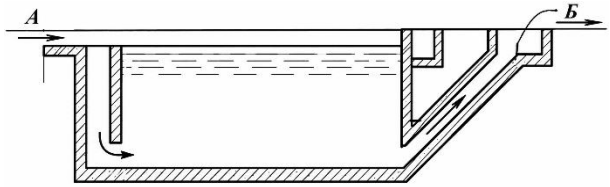


Fig. 7.15. Single-chamber (rectangular) grease trap
A – wastewater inlet; B – treated water outlet

Grease traps of this type are used when treating wastewater with a high fat content or in cases where the fat is easily separated. The duration of wastewater retention in the trap depends on the nature and properties of the fat to be removed. It is usually a few minutes. When discharging wastewater into a reservoir or municipal sewerage system, more thorough treatment of wastewater to remove fatty substances is required. Therefore, such enterprises, which include all fish processing enterprises, install a multi-chamber grease trap, such as a Zunker grease trap (Fig. 7.16). It has additional intermediate partitions that prevent unwanted water flows in the chamber.

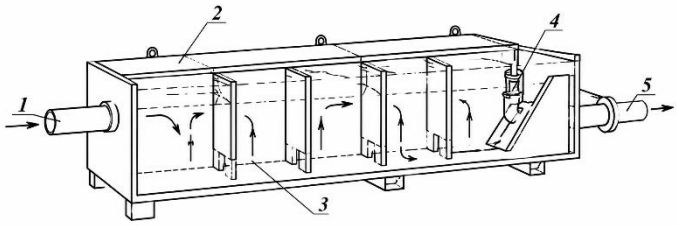


Fig. 7.16. Zunkers grease trap with intermediate partitions (rectangular)
A – wastewater inlet; B – clarified water outlet; 1 – air vent; 2 – main partition wall; 3 – intermediate partition wall; 4 – grease collection tray

This type of grease trap is used to treat wastewater in cases where fatty substances are in a finely dispersed state. Floating grease (or oil) is collected from the surface with a special scraper into a side trough 4, from where it flows into a grease collector.

Practice shows that the use of horizontal grease traps for wastewater from the fish processing industry reduces the fat content by 30–35%. In addition, there are certain difficulties in collecting fat and sediment.

Vertical grease traps with a reactive water distributor and automated grease collection are much more effective. In this case, peripheral wastewater supply and downward flow in the settling zone are carried out. It is equipped with a rotating reactive water distributor to which a skimmer is attached, a central chamber with trays for collecting clarified water and a tray for collecting fat, as well as a pipe for removing sediment.

Wastewater is fed into the jet water distributor and ejected from it under pressure through pipes into the peripheral distribution trough of the grease trap. The rotation of the water distributor, which is carried out due to the reactive force of the outflowing liquid, ensures an even distribution of wastewater around the perimeter of the structure (Fig. 7.17).

Air from the atmosphere is ejected by the jet supplied from the pipe of the reactive water distributor, as a result of which the liquid is aerated in the peripheral distribution trough of the grease trap, which promotes the flotation of grease impurities.

Wastewater flows from the peripheral trough through the water outlet into the settling zone of the grease trap and proceeds to the central chamber. The downward flow promotes better distribution of the liquid throughout the structure, reduces vortex areas and improves the separation of insoluble impurities.

The clarified water is collected in a collection tray and drained from the grease trap through a pipe. Floating impurities are continuously removed from the surface of the grease trap settling zone with a skimmer and discharged into a trough for collecting grease (fat and protein substances captured with it). The settling time at a temperature of 10 – 30 ^{0}C is 10 – 30 minutes.

The moisture content of the sediment discharged from the grease trap is 97 – 98 %, and that of the grease mass is 70 – 80 %. The fat content in the removed fat mass can be 75 – 80 %, in the sediment – 38 % (dry matter). A high fat concentration indicates the possibility of utilising the fat mass and sediment.

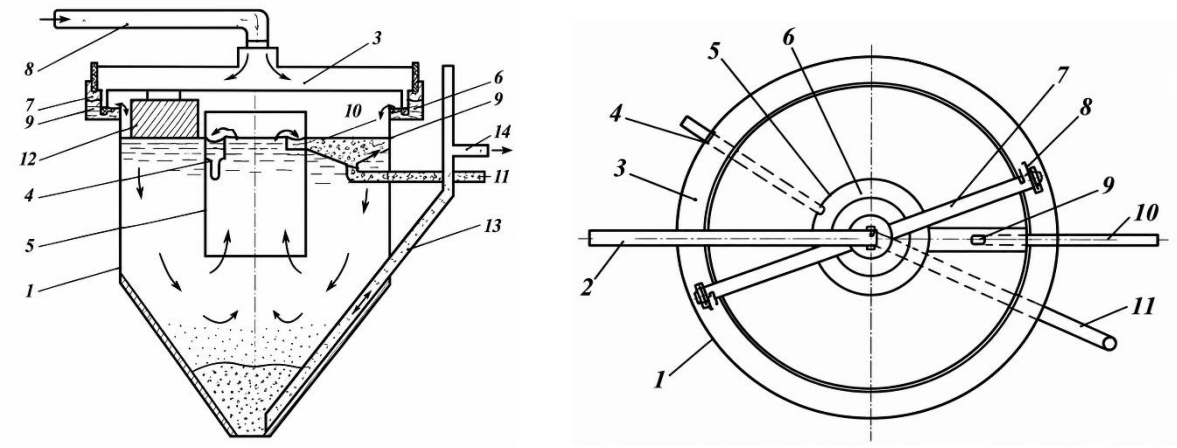


Fig. 7.17. Schematic diagram of a LISI-type grease trap

1 – grease trap housing; 2 – wastewater inlet pipe; 3 – peripheral distribution trough; 4 – clarified water outlet pipe; 5 – central chamber; 6 – clarified water collection trough; 7 – connections; 8 – rotating jet water distributor; 9 – grease collection trough; 10 – grease discharge pipe; 11 – sludge discharge pipe; 12 – defoamer; 13 – grease trap settling zone

It has been established that the degree of reduction in the concentration of fats and suspended solids depends on the initial concentration of these pollutants, the duration of settling and the temperature of the wastewater.

7.1.6. Aerotanks and sedimentation tanks (secondary)

The performance of aerotanks is assessed by the quality of the treated water (BOC_5= 6–8 mg/l, dissolved oxygen content – 3–4 mg/l). The presence of small amounts of nitrates (0.5–1 mg/l) in the treated water indicates the completion of the oxidation process of organic pollutants (Fig. 7.18).

Three key factors influence the quality of wastewater treatment in aeration tanks: aeration period, activated sludge concentration, degree of sludge regeneration, and air flow rate. Due to the fact that the inflow of wastewater varies greatly, the aeration period also varies; the higher the BOC of the wastewater entering the aeration tanks, the longer the aeration period should be. However, the BOC of wastewater also varies widely, so in order to assess the impact of all factors (quantity, quality of wastewater and volume of aeration tanks) on the operation of aeration tanks, the load per 1 m^3 of the aeration tank and per 1 g of ash-free dry matter of sludge according to BOC_5. The higher the load on the aeration tanks, the greater the sludge dose in them should be.

For secondary clarifiers, there is a maximum sludge dose, above which they do not work satisfactorily. Therefore, under high loads, to increase the average sludge dose in aeration facilities, they switch to working with active sludge regeneration (usually providing for the possibility of operating aerotanks without regenerators or with a regenerator volume of 25 and 50 % of the total volume of aerotanks). Depending on the average sludge dose in the facilities, the load per 1 g of ash-free sludge changes.



Fig. 7.18. atmos [8]

Aerotanks at various sewage aeration stations operate with loads of 1 m³ according to BOC_5 from 150 to 700 g/day; the sludge dose in summer is from 1.2 to 1.5 g/l, in winter from 1.6 to 2 g/l, and the sludge dose in regenerators is 3 – 6 g/l. The volume of regenerators is usually 50% of the volume of aeration tanks. The average sludge dose in the structures varies from 2.5 to 4 g/l. At a BOC_5 load of 200 – 250 mg per 1 g of ash-free dry matter of sludge, the aeration tanks operate stably, ensuring high quality of treated wastewater. at higher loads – over 400 mg – the operation of aeration facilities becomes unstable (the sludge index increases, the quality of treated wastewater deteriorates): at loads of 80 – 150 mg, complete nitrification of ammonium salts to nitrates occurs.

The air flow in aeration tanks must be maintained so that the dissolved oxygen content at any point in the aeration tank is not less than 2 mg/l (in sewage aeration tanks – 3 – 6 mg/l, in aeration tanks with complete nitrification – from 7 to 8 mg/l). The air consumption per 1 m^3 of wastewater depends on the BOC of the wastewater entering the aeration tanks: the higher the BOC, the greater the air consumption.

Per 1 kg of BOC_5 removed, the air consumption varies from 40 to 60 m^3, and in aeration tanks with complete nitrification – from 100 to 180 m^3. Hydrobiological analysis of activated sludge in combination with the above indicators allows for a more accurate characterisation of the treatment process in aeration tanks.

The performance of secondary clarifiers is evaluated by the removal of suspended solids and the concentration of return activated sludge. In order for suspended solids to be removed from secondary clarifiers at a rate of no more than 12 mg/l, the water must remain in the clarifier for at least 2.5 hours, and the concentration of activated sludge in the sludge mixture must be 1.2–1.5 g/l, provided that the water and sludge in the aeration tanks are well prepared. If sludge accumulates in secondary clarifiers and consumes dissolved oxygen

intensively, the treated water comes out with a low dissolved oxygen content, and if nitrification occurs in the aeration tanks, denitrification begins in the secondary clarifiers, leading to a significant increase in the removal of suspended solids from the clarifiers. The concentration of return sludge from secondary clarifiers should be 4–6 g/l (Fig. 7.19).



Fig. 7.19. Secondary clarifiers [9]

Filters for additional treatment of biologically treated wastewater. The performance of filters is evaluated by the degree of retention of pollutants in the treated wastewater, primarily suspended solids, which depends on the filtration rate and the quality of the treated water. If the water in the aeration tanks is well prepared, the filters work effectively, removing the activated sludge suspension and, with it, the residual contaminants from the treated wastewater. If the oxidation process in the aeration tanks is disrupted, the filters cannot compensate for their work. To obtain high-quality treated water with an increased content of suspended solids in the water entering the filters, it is necessary to either reduce the filtration rate or increase the number of washes.

Sludge thickeners. The performance of sludge thickeners is assessed by the moisture content of the thickened activated sludge (96.5 – 97.5 %), which depends on the quality of the sludge and the time it spends in the sludge thickener (no more than 12 hours, as the activated sludge rots if left for longer). When the sludge index exceeds 100 mg/l, the performance of the thickeners deteriorates, which leads to malfunctioning of all sludge treatment facilities.

7.1.7. Methane tanks

Methane tanks are cylindrical or rectangular tanks in which sludge from primary or secondary clarifiers undergoes fermentation. The gas released as a result of sludge fermentation is collected in a gas cap located at the top of the gas-tight ceiling, from where it is piped away for use. Methane tanks are constructed of reinforced concrete. They have a conical bottom and, as a rule, a fixed ceiling, although the latter may be movable and floating.

To speed up the fermentation process, the sludge is heated and stirred. The sludge is heated by introducing superheated steam into the sludge chamber or by means of coils through which hot water circulates.

The raw sludge is mixed with the total mass of mature sludge using pumps or ejectors, which remove the sludge from the bottom and feed it to the top using hydroelevators or special mixers. Fresh sludge from the settling tank is fed into

the methane tank from above, and the fermented sludge is removed from the bottom of the tank through a pipe to the sludge drying area.

The fermentation process in a methanogen can be mesophilic – at a temperature of 33°^{0}C – or thermophilic – at a temperature of 53°^{0}C.

As the temperature in methanogens rises, the process of organic matter decomposition accelerates, resulting in a reduction in the size of the structures and a shorter period of sediment retention in them.

There are two main types of methanisation tanks: with a rigid, non-floodable cover; with a floating cover. Methanisation tanks with a floating cover have a number of advantages over those with a rigid cover.

The gas obtained can be used in boiler installations. In a methane tank, 12 – 16 m³ of gas is obtained per 1 m^3 of sediment: 70% methane and 30% carbon dioxide.

The performance of methane tanks is assessed by the gas yield from 1 kg of ash-free substance and fermentation, which depend on the sludge load by actual moisture content and ash-free dry matter per 1 m^3 (Fig. 7.20).



Fig. 7.20. Methane tanks [9]

At higher loads, the fermentation rate decreases. The performance of methane tanks is influenced by the quality of the raw materials loaded, the ratio of raw sludge to active sludge, their moisture content, ash content and chemical composition (fat, protein and carbohydrate content). When the chemical composition of the sludge changes, especially when the fat content decreases and the protein content increases, the gas yield decreases. In addition to gas yield, the fermentation process is controlled and evaluated by the sludge liquid, in which the amount of fatty acids, alkalinity and nitrogen of ammonium salts are determined. If the process is disrupted, the alkalinity and nitrogen of ammonium salts decrease, and the fatty acid content increases.

7.1.8. Fermented sludge thickeners

The performance of thickeners is assessed by the moisture content of the thickened sludge and the content of suspended solids in the effluent, which depends on the quantity and quality of the discharged sludge fed to the thickener. When the thickeners are working satisfactorily, the suspended solids content in the effluent should not exceed 1.5 g/l, and the moisture content of the thermophilic fermented mixture of sludge and slurry should be 95.5%.

If the compactors malfunction, the suspended solids content in the effluent exceeds 3 g/l, which leads to an increased load on the biological treatment facilities. In such cases, the seal must be switched off, cleaned of sediment and put back into operation with a load on the sediment that is 2 times less than the design load.

7.1.9. Vacuum filters

The performance of vacuum filters is evaluated based on the productivity and moisture content of the cake obtained. The productivity of vacuum filters depends on the quality of the incoming raw materials: the ratio of raw sludge and active sludge in the fermented sludge, moisture content and ash content. The highest productivity of vacuum filters (35 kg/m^2/hour) can be achieved when raw sludge fermented in methane tanks is supplied. If the active sludge content in the fermented mixture of sludge and sludge increases, productivity decreases. As the moisture content of the compacted sludge increases, the productivity of vacuum filters decreases. According to data from aeration stations, the average productivity of vacuum filters is 20 – 22 kg/m^2/hour, obtained at a moisture content of compacted sludge of 95 – 95.5 %, chlorinated iron doses of 4.5–6 % and lime milk of 13–18%. If the moisture content of the sludge fed to the vacuum filters is reduced to 94–94.5%, the productivity increases to 30–35 kg/m^2/hour, and if the moisture content of the sludge fed increases above 96%, productivity decreases to 12–15 kg/m^2/hour.

7.1.10. Thermal drying in drum dryers

The performance of drum dryers is evaluated based on productivity, moisture content, and the amount of dry matter in the dried sediment. Productivity largely depends on the moisture content of the cake entering the dryer and gas consumption. If the gas burners do not increase the temperature of the flue gases supplied to the dryer, then as the moisture content of the cake increases, so does the moisture content of the dried sediment.

The materials obtained during the control are compiled monthly by laboratory and workshop employees in tables, on the basis of which quarterly, semi-annual, nine-month and annual reports, in which the analytical data is linked to the main operating indicators (water inflow, air consumption, electricity consumption, etc.) and compared with the planned targets.

i7.2. Physical and chemical wastewater treatment

Physical and chemical treatment methods play a significant role in the treatment of industrial wastewater. They are used both independently and in combination with mechanical, chemical and biological methods.

Physical-chemical treatment methods include coagulation, flocculation, sorption, flotation, hyperfiltration, magnetic treatment, etc., as well as methods involving the application of an electric field – electroflotation and electrocoagulation.

Chemical e treatment of wastewater

Chemical or reagent treatment of wastewater is one of the oldest methods of treatment. In addition to neutralising wastewater, it allows for the removal of suspended solids that cannot be precipitated by mechanical treatment methods, the separation of colloidal and dissolved organic substances, the decolourisation and disinfection of wastewater, the elimination of unpleasant odours, and partially neutralise substances formed during water disinfection with chlorine. Chemical treatment is usually used in combination with subsequent settling or flotation of wastewater to remove aggregated suspended solids.

Coagulation is the sticking together of particles of a colloidal system when they collide during thermal motion, mixing or directed movement in an external force field. Coagulation results in the formation of aggregates – larger (secondary) particles consisting of clusters of small (primary) particles. Thus, coagulation is accompanied by a progressive enlargement of particles and a decrease in their total number in the volume of wastewater. The sticking together of homogeneous particles is called *homocoagulation,* and that of heterogeneous particles is called *heterocoagulation*.

Industrial wastewater is mostly weakly concentrated emulsions or suspensions containing colloidal particles ranging in size from 0.001 to 0.1 micrometres, as well as particles ranging in size from 10 micrometres and above. During mechanical treatment, particles with a size of 10 μm and larger are easily removed from wastewater; finely dispersed and colloidal particles are practically not removed. Thus, wastewater from fish processing plants after mechanical treatment is an aggregatively stable system. Coagulation methods are used to treat it. This disrupts the aggregate stability, forming larger particle aggregates that are removed from the wastewater by mechanical methods.

One type of coagulation is *flocculation*, in which small particles in a suspended state, under the influence of specially added substances (flocculants), form loose flaky aggregates that settle intensively.

The effectiveness of coagulation depends on many factors: the type of colloidal particles, their concentration and degree of dispersion, the presence of electrolytes and other impurities in the wastewater, as well as the value of the electrokinetic potential.

Colloidal particles, which are a collection of a large number of molecules of a substance contained in wastewater in a dispersed state, firmly hold the layer of water covering them during mixing. With a large specific surface area, colloidal

particles adsorb ions in the water, mainly of the same sign, which significantly reduce the free surface energy of the colloidal particles. The formation of colloidal particles is preceded by the formation of a solid phase (core) that adsorbs potential-determining ions from the solution.

Ions directly adjacent to the core form a layer of surface-core ions, or the so-called adsorption layer. As a result of ion absorption, the surface of the core acquires a charge. This layer may contain a small number of oppositely charged ions due to the electrical attraction between opposite electrical charges, the total charge of which, however, does not compensate for the charge of the surface-nuclear ions. Thus, a colloidal particle, or granule, is formed. Due to the fact that an electric charge is created at the boundary of the adsorption layer, a diffusion layer is formed around the granule (core) with the adsorption layer, which contains the remaining oppositely charged ions that compensate for the charge of the granules. The granule together with the diffusion layer is called a micelle, which is electrically neutral.

At the boundary of the adsorption layer, the potential decreases by an amount equal to the sum of the charges of oppositely charged ions in the adsorption layer. The potential at the boundary of the adsorption layer is called the electrokinetic potential.

Diffusion forces act on colloidal particles, and the particles tend to distribute themselves evenly throughout the entire volume of the liquid phase. The presence of electric charges of the same sign on the particles causes them to repel each other. At the same time, there are molecular forces of interaction between colloidal particles, which manifest themselves only at small distances between particles. When the electric charge of the particles decreases, the repulsive forces decrease and it becomes possible for the particles to stick together – the process of colloid coagulation.

The separation of substances belonging to the solid phase (the smallest particles of fish, auxiliary materials), as well as colloidal compounds (proteins) and metal salts, i.e. their coagulation, can occur as a result of the interaction of these compounds during the mixing of two different types of wastewater (with $pH>7$ and $pH<7$).

Wastewater coagulation is based on neutralising the negative charges of colloidal particles with positive charges of insoluble metal hydroxides or calcium carbonate. Neutralisation of charges disrupts the stability of colloidal particles and causes sols to transform into gels. The initial particles formed become coagulation centres, grow to large sizes, and easily and quickly settle or float in the form of flakes. Contaminants in wastewater coagulated in this way are easily separated from the effluent in settling tanks or flotation units.

One method of reducing the ξ-potential of a colloidal system is to increase the concentration of electrolytes in the water. The ability of an electrolyte to cause coagulation of a colloidal system increases with the valence of the coagulating ion, which has a charge opposite to that of the colloidal particles. The ratio of the coagulating ability of mono-, divalent and trivalent ions is approximately 1:30:1000.

Chloride and sulphate compounds of ferrous and ferric iron, aluminium sulphate and lime are commonly used as coagulants. Lime is used for two purposes: as a coagulant and to adjust the pH of effluents when using ferrous and ferric salts of iron and aluminium.

Depending on the conditions of sol formation, the potential of determining ions and counterions may change places. Thus, the aluminium hydroxide sol formed during the hydrolysis of aluminium salts is positively charged at low pH values of water and negatively charged at high pH values.

In most cases, coagulants are salts of weak bases and strong acids. When dissolved in water, hydrolysis occurs and poorly soluble bases are formed – aluminium and iron hydroxides. At the same time, due to the shift in the dissociation equilibrium, hydrogen ions (H^+) accumulate in water and acid appears in the solution. The solubility of aluminium and iron hydroxides is very low. They are separated from the solution, forming colloidal particles (diluted hydroxide sols), which, under the influence of electrolytes dissolved in water, coagulate and precipitate together with colloidal impurities.

The rate of hydrolysis of metal salts is proportional to the concentration of metal cations, but since it is always low, the rate of hydrolysis is proportional to the dose of coagulant introduced into the wastewater. With an increase in temperature, the hydrolysis rate increases approximately twice every 10 ^{0}C. To quantitatively characterise the degree of hydrolysis, it is convenient to use the concentration of hydrogen ions in the solution. By changing the pH of the solution, the course of the process can be regulated.

Aluminium and iron hydroxides have a solubility of 0.6–1.5 mg/dm^3, but at a coagulant dose of 150 mg/dm^3 they can inhibit the coagulation process, so bicarbonate salts dissolved in water have a positive buffering effect. They form a buffer system with a pH close to neutral. When the buffer mixture is insufficient to neutralise the acid formed, the water is alkalised by adding lime, soda, etc. The alkalising effect is explained by the binding of hydrogen ions by hydroxyl ions of lime, and when soda is added, by the binding of hydrogen ions to bicarbonate ions.

The concentration of hydrogen ions at which aluminium hydrolysis has maximum solubility is in the range of 6.5–7.5. Aluminium hydroxide precipitation begins at pH = 3.

During the coagulation of acidic and neutral wastewater impurities containing small amounts of hydrocarbonates, it is recommended to use mixtures of aluminium sulphate and sodium aluminate to neutralise the hydrogen ions formed during the hydrolysis of aluminium sulphate. In this case, the hydrogen ions accumulated in the water will be neutralised by the hydroxyl ions formed during the hydrolysis of sodium aluminate.

When aluminium and iron salts are used as coagulants, poorly soluble hydroxides are formed as a result of the hydrolysis reaction.

That is, when using ferrous iron for the normal course of the reaction, the presence of oxygen in the water is necessary. The acid formed during hydrolysis is neutralised by lime. The neutralisation of acids formed during the hydrolysis of

coagulants can proceed due to the alkaline reserve of wastewater. In order to reduce the consumption of coagulant, the coagulation process should be carried out within the range of optimal pH of the medium:

- for $Al(OH)_3$ – 4.5 – 7;
- $Fe(OH)_2$ – 8.5 – 10.5;
- $Fe(OH)_3$ – 4 – 6 and 8 – 10.

Various mineral coagulants are used to treat industrial wastewater:

1) Aluminium salts. Aluminium sulphate (alumina) $A1_2$ $(8O_4)_3$ $\bullet 18H_2$ O (density – 1.62 t/m^3, bulk density – 1.05 – 1.1 t/m^3, solubility in water at a temperature of 20 ^{0}C – 362 g/dm^3). *Sodium aluminate* $NaAlO_2$, potassium aluminate [$A1K(8O_4)_2 \bullet 18H_2O$] and ammonium aluminates [$A1(NH_4)(SO(_4)_2 \bullet 12H_2O$] are less expensive and less scarce than aluminium sulphate.

2) Iron salts. Divalent iron sulphate, or iron vitriol $FeSO_4 \bullet 7H_2O$ (density – 3 t/m^3, bulk density – 1.9 t/m^3, solubility in water at a temperature of 20 ^{0}C – 269 g/dm^3, *iron hydroxide* – dense, heavy flakes that settle quickly, which is an undoubted advantage of its use, *iron chloride* $FeCl_3 \bullet 6H_2$ O, *iron sulphate* $Fe_2(SO_4)_3 \bullet 9H_2O$.

3) Magnesium salts. Magnesium chloride $MgCl_3 \bullet 6H_2$ O, *magnesium sulphate* $MgSO_4 \bullet 7H_2O$.

4) Lime.

The coagulation process is optimal at pH > 6. The coagulant dose depends on the type of coagulant, the composition of the wastewater, and the required degree of purification. The sludge formed after coagulation consists of flakes ranging in size from a few micrometres to several millimetres. The loose spatial structure of the sediment flakes causes them to have high moisture content – up to 96–99.9%. The density of the sediment flakes is usually 1.01–1.03 t/m^3. The coagulant dose can reach 1–4 g/dm^3 for highly concentrated and intensely coloured waters. The volume of sludge formed as a result of coagulation reaches 10–20% of the volume of treated wastewater. The following concentrations of the most commonly used reagents are recommended for the treatment of wastewater from fish processing plants: $A1_2(SO_4)_3$ – 2.5 g/dm^3, $CaCO_3$ – 2.5 g/dm^3, $FeCl_3$ – 100 mg/dm^3.

The coagulation method of treatment is mainly used for small volumes of wastewater and when cheap coagulants are available. The coagulation method ensures the separation of suspension or emulsion from wastewater. Coagulated impurities can be separated by sedimentation or flotation. When using coagulation of wastewater from fish processing plants with subsequent settling for 1.5 hours, it is possible to achieve a purification effect of 72–80% for suspended and ether-soluble substances, 42–60% for COD, and 60–70% for BOC. When using coagulation followed by pressure flotation for 20–30 minutes, the purification effect can be 80–90% for suspended and ether-soluble substances and 70–75% for COD.

The expansion of the optimal coagulation areas (in terms of pH and temperature) is facilitated by flocculants, which increase the density and strength of the flocs formed, reduce the consumption of coagulants, and increase the

reliability and throughput of treatment facilities. They belong to the class of linear polymers, which are characterised by a chain-like form of macromolecules. The molecular weight of flocculants ranges from tens of thousands to several million. The length of the chain, consisting of a series of identical links, is hundreds of nanometres. They are highly soluble in water. Their aqueous solutions are true solutions, i.e. homogeneous thermodynamically stable systems. When dissolved in wastewater, flocculants can be in a non-ionised or ionised state. The latter are called soluble polyelectrolytes. Depending on the composition of the polar groups, flocculants can be:

- *non-ionic* – polymers containing non-ionic groups: -OH, CO (starch, oxyethylcellulose, polyvinyl alcohol, polyacrylonitrile, etc.);
- *anionic* – polymers containing anionic groups: COOH, $-SO_3H$, OSO_3H (activated silicic acid, sodium polyacrylate, sodium alginate, lignosulphonates, etc.);
- *cationic* – polymers containing cationic groups: $-NH_2$, =NH (polyethyleneamine, vinylpyridine copolymers BA-2, BA-102, BA-212, etc.);
- *amphoteric* – polymers containing both anionic and cationic groups (polyacrylamide, proteins, etc.).

The speed and efficiency of the flocculation process depends on the composition of the wastewater, its temperature, the intensity of mixing, and the sequence of adding coagulants and flocculants, etc. Flocculant doses are usually 0.1–1.0 mg/dm^3. For example, the use of polyacrylamide additives at a concentration of 1 mg/dm^3 can double the specific load on the settling tanks. Physical methods of intensifying the coagulation process include: aeration, application of electric and magnetic fields, ultrasound, and ionising radiation.

The process of wastewater treatment by coagulation and flocculation includes the preparation of aqueous solutions of coagulants and flocculants, their dosing, mixing with the entire volume of wastewater, the formation of flocs, and the separation of flocs from it.

The reagent management at treatment facilities includes storage facilities for coagulants and flocculants. Currently, the so-called wet storage of coagulants in the form of concentrated solutions in containers installed in heated rooms is widely used.

The preparation of the reagent solution (or suspensions) is carried out in solution and consumption tanks, the number of which is taken to be at least three and two, respectively. Coagulants are dissolved in water in solution tanks using compressed air or mechanical stirring.

Pieces of coagulant are loaded into a solution tank with a bottom made of wooden grates, and the saturated coagulant solution flows through the bottom into the consumption tank. Tap water is added to this tank to dilute the solution to the required concentration. To accelerate the dissolution of the reagent pieces, compressed air is supplied under the grates through a plastic pipe. Through the same pipe, compressed air enters a system of perforated pipes laid along the bottom of the discharge tank to mix the solution in order to maintain its uniform

concentration. The connected solution storage tank must have two compartments so that the supply of solution is not interrupted when it is being mixed in one of the compartments.

From the solution tanks, the coagulant solutions are pumped into the supply tanks, and from there they are dosed into the treated water using dosing devices of various designs. Part of the water, separated in a certain amount from the total flow at the distribution weir, enters the dosing device's water meter tank (the other, larger part enters the mixer directly). The water leaves the tank through a pipe with a diaphragm and is directed through a funnel into the mixer. The tank has a float which, with the help of a cable thrown over blocks, maintains the dosing pipe with a diaphragm at a certain height. Through this tube, a reagent solution flows out of the second tank, the level of which is kept constant in the tank by a ball valve. If the amount of water entering for treatment increases, the water level in the tank rises, the float rises, the dosing tube descends, and the flow rate of the reagent solution increases in proportion to the flow rate of the treated water. In the raw wastewater tank, the settling chamber is separated by a partition. Coagulants are added to the treated water in the form of 1-10% solutions, and flocculants in the form of 0.1 – 1 % solutions. The treated wastewater remains in the mixers for 1 – 2 minutes. The pipes or trays that carry water from the mixers to the flocculation and clarification chambers are designed for a wastewater flow rate of 0.8–1.0 m/s and a residence time of no more than two minutes.

After mixing the wastewater with coagulants, the flocculation process begins in special chambers, for example, in horizontal baffle chambers. In these chambers, the wastewater flows through several sequentially connected corridors. Mixing is carried out by means of eight to ten turns at a water flow rate of approximately 0.2–0.3 m/s in the first corridor, with a subsequent reduction in speed so that it does not exceed 0.1 m/s in the last corridor. The water remains in these chambers for 20–30 minutes. The height of the chamber is determined by the height of the sedimentation tank, and the width of the corridors must be at least 0.7 m.

Further clarification of wastewater is carried out in settling tanks. The most expedient two-stage wastewater settling scheme is used. At the first stage, simple settling is carried out in a settling tank without a coagulant, at the second stage – wastewater treatment with coagulants and flocculants from followed by settling in a settling tank.

Based on the concentration of suspended solids in the treated wastewater C_n, the known calculated velocity of the upward water flow in the clarification zone V_{clar}, the reference concentration of suspended solids in the suspended layer C_e (at a water velocity of 1 mm/s and a temperature of 20 ^{0}C) and the concentration of suspended solids in the sediment after its compaction $C_{init,}$ the water flow rate can be determined.

The calculated flow rate of wastewater (SR_{rozr}• m^3/s) passing through the clarifier is determined by the formula:

$$C_{calc} = Q_{light} [1 + (C_n – C_k)/C_{init}],$$

where Q_{light} – is the wastewater flow rate leaving the clarifier, m³/h;
C_k – final concentration of suspended solids in wastewater, g/m³.

Advantages of the reagent treatment method:

- the equipment and apparatus are simple, and their installation costs are low (approximately 50% less than biological treatment plants);
- the method can be used with significant fluctuations in the quantity and quality of wastewater;
- unlike biological treatment, interruptions in the coagulation treatment process are insignificant.

Disadvantages:

- incomplete removal of organic substances from wastewater;
- significant consumption of coagulants;
- large volume of sludge produced, complexity of its treatment and subsequent storage;
- increased mineralisation of treated wastewater;
- additional storage space for reagents;
- consumption of labour and transport for the delivery and disposal of coagulants.

Flotation is the process of molecular adhesion of flotation material particles to the interface between two phases, usually gas (more often air) and liquid – wastewater. The process of treating industrial wastewater containing fine suspensions, proteins, fats, and oils by flotation involves the formation of particle-bubble complexes, the flotation of these complexes, and the removal of the resulting foam layer from the surface of the treated liquid.

The adhesion of a particle in wastewater to the surface of a gas bubble is only possible when the particle is not wetted or poorly wetted by water. Such particles include grease and oil. Suspended particles containing proteins have hydrophilic properties. Hydrate shells form on their surface, preventing particles from adhering to air bubbles. However, proteins are amphoteric and heteropolar, with hydrophobic and hydrophilic properties at different ends of the radicals. In addition, the composition of contaminating particles, in addition to protein, includes fats, forming lipoprotein complexes, so they can adhere to bubbles at the interface of three phases: particle – air – water, and rise to the surface of the liquid.

The external manifestation of a liquid's ability to wet is the surface tension at the interface with air, as well as the difference in polarities at the interface between the liquid and solid phases.

Surface tension is equal to the force acting in the plane tangent to the surface of the liquid per unit length of the contour limiting this surface and is measured in J/m² or N/m, denoted by the letter σ. Its supply to the surface (σ•S) is called free energy.

The flotation process is effective at σ = 60–65 mkn/m. The degree of wetting by water of solid or gas particles suspended in water is characterised by the value

of the contact angle Θ (Fig. 7.21). The larger the angle Θ, the more hydrophobic the surface of the particle, i.e., the greater the probability of adhesion to it and the strength of retention of air bubbles on its surface. Such particles have low wettability and float easily.

The size, number and uniformity of air bubbles in the effluent are of great importance during flotation. The optimal size of air bubbles is 15–30 micrometres, and the maximum size is 100–200 micrometres. As the number of bubbles increases, the distance between them and the particles decreases, increasing the possibility of collision and adhesion. As the size of the bubbles decreases, their surface area increases, as does the possibility of collision with contaminant particles. However, the minimum size of the bubbles must be comparable to the contaminant particles, otherwise the flotation complex will not float or the process will slow down significantly.

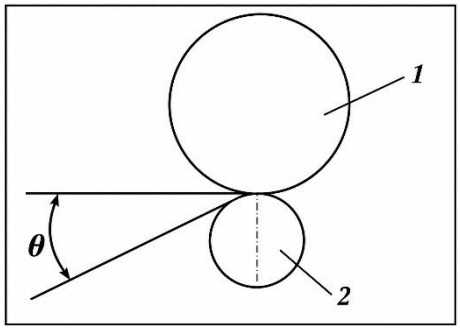


Fig. 7.21. Diagram of the adhesion of air bubble 1 to particle 2 suspended in water

Typically, the surface tension of wastewater is compared to the surface tension of distilled water (73 mN/m). The surface tension of wastewater from fish processing plants is reduced due to the presence of detergents, which allows the flotation method to be used for their purification. The presence of foaming detergents and protein substances with surface-active properties causes the foam to be stable, which makes it possible to remove it from the surface of the flotation tank using defoaming devices. Floating to the surface, the foam is collected in a special receiver, where it is subsequently destroyed, forming a liquid saturated with pollutants – *flotation concentrate*. It is subjected to decantation, during which part of the contaminants float and the other part settles. The pollutants concentrated in the floating layer and sediment are disposed of. The composition and amount of pollutants depends on the properties of the wastewater.

In the practice of industrial wastewater treatment, various design schemes, techniques and methods of flotation have been developed. There are the following methods of flotation treatment of wastewater:

- flotation with air separation from the solution (vacuum, pressure and airlift flotation units);
- flotation with mechanical air dispersion (impeller, pressureless and pneumatic flotation units);
- flotation with air supply through porous materials;
- electroflotation.

Flotation units can consist of one or two compartments (chambers). In single-chamber units, the same compartment simultaneously saturates the liquid with air bubbles and floats the floating contaminants. In two-chamber plants, consisting of a receiving and settling compartments, the formation of bubbles and «bubble-particle» aggregates occurs in the first compartment, and in the second - the flotation of foam (foam mass) and clarification of the liquid.

Flotation with air separation from the solution. This type of flotation is used in the treatment of industrial wastewater containing very fine particles of contaminants, as it allows the formation of the finest air bubbles. The essence of the method is to create a supersaturated air solution in the wastewater. The air released from such a solution forms microbubbles that float the contaminants contained in the wastewater. The amount of air to be released from the saturated solution to ensure the necessary flotation efficiency is usually 1–5% of the volume of wastewater being treated.

Vacuum flotation is used when the concentration of contaminants in wastewater does not exceed 250 mg/dm^3. The peculiarity of the method is that the formation of gas bubbles, their adhesion to pollutant particles and the floating of the resulting aggregates – «bubble-particles» – occurs in a calm environment, where the probability of their destruction is minimal. The energy costs for saturating the liquid with air and forming and crushing air bubbles are also minimal. The disadvantages of the method include the need to construct hermetically sealed devices, the complexity of operating the installations and their limited range of application, mainly for the additional treatment of wastewater.

Wastewater is pre-saturated with liquid air for 1–2 minutes in an aeration chamber, from where it enters a deaerator to remove undissolved air. The wastewater then enters the flotation chamber, where a vacuum (0.02–0.03 MPa) is maintained. In the flotation chamber, air dissolved at atmospheric pressure boils in the form of microbubbles and carries the contaminant particles into the foam layer. The wastewater remains in the flotation chamber for 20 minutes. The accumulated foam is removed by rotating scrapers into a foam collector. To discharge the treated wastewater, the necessary difference in levels in the flotation chamber and the receiving tank is provided, or a pump is installed.

Pressure flotation has a wider range of applications, as it allows the degree of air supersaturation to be adjusted according to the required wastewater treatment efficiency at an initial concentration of pollutants of 4–5 g/dm^3 and above. In pressure flotation, wastewater is fed into the pressure tank by a centrifugal pump (Fig. 7.22.).

An ejector for supplying atmospheric air is mounted on the suction pipe of the pump. The air entering the pump dissolves in the liquid due to increased pressure and, under the influence of vortex flows, is converted into small bubbles, which then enter the pressure tank through the discharge pipe and form a contact surface with the liquid. Complete dissolution of air (up to 5%) is ensured by the presence of a pressure tank in the system, where the effluent is held for 2 – 3 minutes under a constant pressure of 0.196-0.49 MPa and enters the open flotation chamber through an automatic pressure regulator. As a result of a sharp drop in

pressure to atmospheric pressure in the receiving part of the flotation chamber, an air-conducting emulsion is formed due to microbubbles of air released from the solution. These bubbles, adhering to the particles of the suspension and other undissolved, floatable impurities, carry most of them into the foam layer.

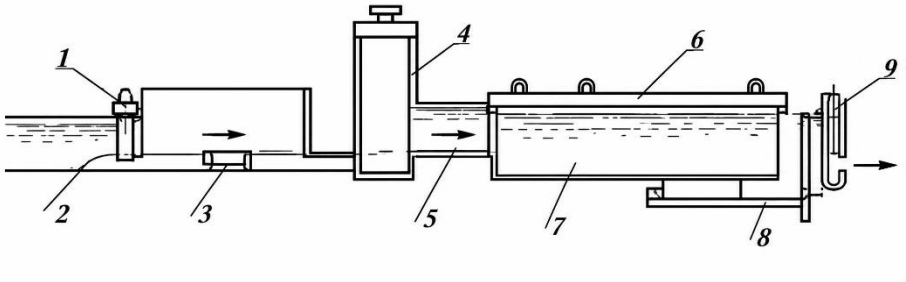


Fig. 7.22. Schematic diagram of a pressure flotation unit

1 – collection tank; 2 – float sensor for the water flow regulator; 3 – air ejector; 4 – pump; 5 – automatic water flow regulator; 6 – pressure tank; 7 – automatic pressure regulator; 8 – discharge chamber; 9 – flotation chamber; 10 – scraper conveyor; 11 – pipeline for removing foam for treatment; 12 – discharge chamber with a wastewater level regulator in the flotation chamber; 13 – decanted water; 14 – clarified wastewater; 15 – foam collection pocket

The foam from the surface of the flotation chamber water is collected by a scraper conveyor into a foam collection pocket. The clarified water is removed from the bottom of the chamber. During the settling of the foam product in the foam collection pocket, water is released. Decanted water is a heavily contaminated effluent that is returned to the settling station. Under mechanical action (a vibrating rod is lowered into the foam), the foam is easily destroyed, its volume is reduced by an average of 4 times, turning into a fatty mass.

If the amount of air that needs to be passed through the pump exceeds 2–5% of the amount of liquid being pumped, then air is introduced into the wastewater using an air ejector, which provides a high degree of air bubble fragmentation due to the dispersing action of the vortex flows created by the pump impeller.

The air ejector operates on the principle of a water jet pump, i.e. air is sucked in by the water pressure created by the pump. A rotameter is installed on the suction pipe of the ejector to change the air flow rate.

The pressure tank is a closed cylindrical vessel. Inside the tank there is a ring partition with holes and a pipe with a nozzle for water intake. A pressure gauge and a tap for removing air undissolved in water are installed on the upper bottom, and a tap for emptying the tank is installed on the lower bottom.

The area of the flotation chamber should be calculated based on a hydraulic load of 6–10 m^3/hour per 1 $m^2$of the chamber surface area.

When designing flotation units for wastewater treatment with a flow rate of up to 100 m^3/hour, rectangular chambers with a depth of 1–1.5 m are used, and for flow rates above 100 m^3/hour, radial flotation units with a depth of at least 3 m are used (Fig. 7.23).

The depth of the flotation and settling zones is set at no less than 1.5 m, and

the duration of water stay in them is no less than 5 and 15 minutes, respectively. Radial flotation units are used in the fish processing industry.

Wastewater saturated with air enters the flotation unit from below through a rotating water distributor. Air bubbles released from the water float up together with the contaminant particles. A rotating mechanism rakes the foam into a trough and removes it. The treated water is drained from the bottom and flows through vertical channels into a discharge ring trough. The capacity of a single flotation unit should not exceed 1000 m³/hour.

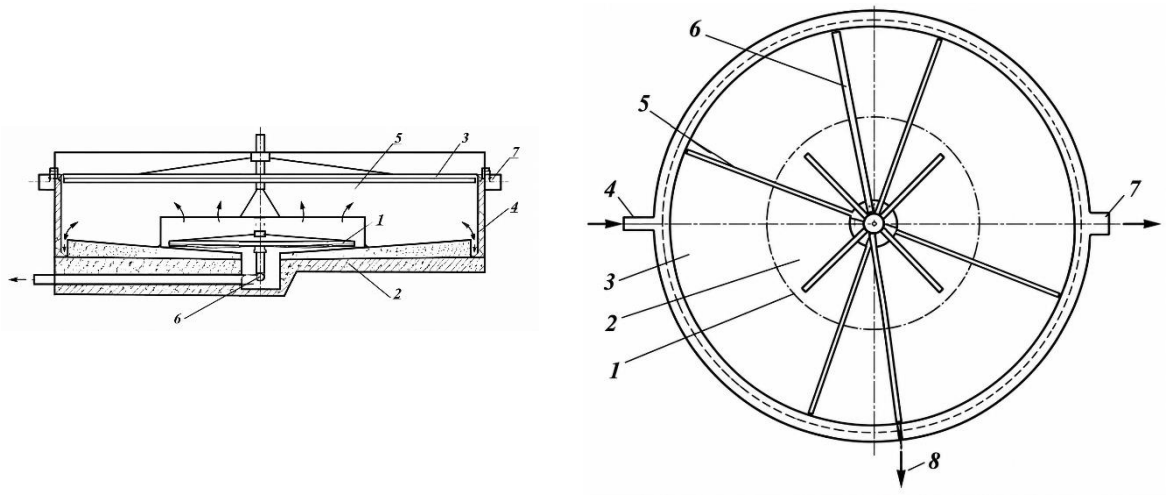


Fig. 7.23. Radial flotation unit

1 – rotating water distributor; 2 – flotation chamber; 3 – settling chamber; 4 – sludge discharge; 5 – foam skimming mechanism; 6 – foam collection trough; 7 – clarified wastewater outlet; 8 – foam discharge; 9 – wastewater inlet

Pressure flotation is used at all treatment plants to treat industrial wastewater from fish processing enterprises. The purification effect for suspended solids reaches 75–80%, for ether-soluble substances – 84–86%, and for COD – 45–60%.

During flotation, foam is formed, the amount of which can reach 12% of the wastewater mass. During foam extinction, up to 1.5% of flotation concentrate is formed, of which 1.2% is decanted water.

Calculation of pressure flotation plants

1) The volume of the pressure tank (W, m³) is determined by the formula:

$$W_{p.t.} = \mathbf{Q} \cdot t_s/60,$$

where Q – is the useful capacity of the treatment plant, m/hour;

t_s – time of saturation of wastewater with air, min; $t_s = 2 – 3$ min.

2) The saturation pressure is 0.245 – 0.343 MPa.

3) The amount of air supplied for saturation is 50 dm³ /m³of treated water.

4) The volume of the flotation tank (in m³) is determined by the formula:

$$W_{f.t.} = \mathbf{Q} \cdot (t_{t.s.} + t_{d.f.})/60,$$

where $t_{r.a.}$ – time spent by wastewater in the flotation tank receiving chamber,

2–3 min;

$t_{d.f.}$ – duration of flotation, 20 – 30 min.

When designing a flotation clarifier, the following dimensions should be used:

h (working depth of the clarifier) – 1.3 – 2 m;

b (width of the chamber) – 0.1 – 2.0 m;

l/b (length to width ratio) – from 3 to 6.

Foam is removed from the surface of wastewater by a scraper mechanism at a speed of 0.01–0.2 m/s. The volume of the foam extinguishing tank should be calculated as 8% of the hourly capacity of the plant and the time the foam remains in it – 2–3 hours. The amount of decanted water is 0.7% of the capacity of the treatment plant, and the amount of fat mass removed is 0.5–0.7%. It is recommended to provide for forced foam extinguishing after settling for 20–30 minutes.

The collected fat mass is sent for industrial processing to obtain technical fat and lubricants. The sediment is sent for mechanical disposal using sedimentation centrifuges, with subsequent use for the production of fish meal for animal feed, or sent in its raw form for fermentation in a clarifier-digester chamber.

Flotation with mechanical air dispersion. When the air jet moves through the water, an intense vortex motion is created, under the influence of which the air jet breaks up into individual bubbles. Vigorous mixing of wastewater in flotation impeller units creates a large number of small vortex flows in it, which makes it possible to obtain bubbles of a certain size.

When using a two-chamber direct-flow flotation unit, wastewater from the receiving pocket enters the impeller, into which air is sucked through a pipe. Above the impeller is a stator in the form of a disc with holes for internal water circulation. The water and air mixed in the impeller are discharged through the stator. The grids located around the stator promote finer dispersion of air in water. Air bubbles settle above the grid. Foam containing floated particles is removed by a blade skimmer. From the first chamber, water flows into the second chamber of the same design, where additional wastewater treatment takes place.

The degree of air dispersion depends on the circumferential speed of the impeller, which is taken to be 12–15 m/s. The diameter of the impeller should not exceed 75 cm, and the impeller service area should not exceed 6 d_i (where d_i is the impeller diameter), the height of the flotation chamber H_f is taken to be 1.5–3 m, and the flotation time t_f is = 20–30 min.

The volume of the flotation chamber (W, m^3) is determined by the formula:

$$W_f = 0.0259 \cdot Q \cdot t_f,$$

where Q – is the wastewater flow rate, m^3/hour.

The throughput capacity of the flotation unit (Q_f, m^3/year) is determined by the formula:

$$Q_f = 36 d_i^2 \cdot H_f / 0.025\ t_f$$

Specific air consumption Wood = 40 – 50 m^3/hour per 1 m^2 of the flotation chamber surface area. The amount of air supplied by the impeller (Ov, m^3/hour) is determined by the formula:

$$Q_v = 0.000278 \bullet W_{ac} \bullet \mathbf{f},$$

where **f –** is the water surface area of the flotation chamber, m^2.

The required number of flotation chambers n_{fc} is determined by the ratio:

$$n_{fc} = Q/Q_v$$

The use of impeller installations is advisable when treating wastewater with a high concentration of fats and oils (more than 2–3 g/dm^3), in particular in fat purification, veterinary and medical fish oil production.

The foam formed in the machine chambers is continuously removed from the surface of the wastewater by a skimming device into a special trough, where it begins to break down and turn into a liquid – flotation concentrate. The amount of flotation concentrate is 11–30% of the treated water flow. Then the foam and the flotation concentrate formed flow into settling tanks – decanters.

In them, within 60–90 minutes, the foam breaks down, and the flotation concentrate separates into a floating fat mass, sediment, and decanted water. The fat mass has a moisture content of about 85%. It is used to obtain technical fat, and the decanted water is sent back for purification. Impeller-type flotation machines are more efficient than grease traps. The effect of removing fats and suspended solids is 62% and 64% for a flotation duration of 8–10 minutes, and 77% and 68% for 20 minutes.

In addition to the formation of large amounts of foam, the disadvantages of flotation machines include high electricity consumption – up to 1.3 kWh per 1 m^3 of treated wastewater – and increased noise levels during operation.

Flotation with air supply through porous materials. It is distinguished by the simplicity of the equipment design and relatively low energy consumption. Air is supplied to the flotation chamber through fine-pored filter plates, pipes, and nozzles located at the bottom of the chamber. The size of the holes should be 4–20 micrometres, the air pressure 0.1–0.2 MPa, the flotation time 20–30 minutes, and the air flow rate is determined experimentally.

The working level of the treated wastewater before flotation is 1.5–2 m. The disadvantage of this method is the possibility of clogging and clogging of pores, as well as the difficulty of selecting fine-pored materials that provide the release of small air bubbles of similar sizes, therefore, the possibilities of use are limited.

Pneumatic flotation units. They are used in the treatment of wastewater containing dissolved impurities that are aggressive to mechanisms (pumps, impellers, etc.) with moving parts.

Air bubbles are crushed by releasing air into the flotation chamber through nozzles located on air distribution pipes and placed on the bottom of the flotation chamber at a distance of 0.25–0.3 m from each other. The diameter of the nozzle holes is 1–1.2 mm, the working pressure in front of them is 0.3–0.5 MPa, and the

jet exit velocity is 100–200 m/s. The depth of the flotation cell is taken to be 3–4 m. The volume of the flotation cell $W_{(ф)}$is determined by the formula:

$$W_f = Q \cdot t_f/[60 \cdot (1 - K_A)],$$

where t_f – is the duration of flotation, 15–20 minutes;
K_A –is the aeration coefficient, equal to 0.2–0.3.

The required air flow depends on the intensity of aeration and is approximately equal to 15–20 m^3/m^2 per hour. The required number of nozzles n_n is determined by the formula:

$$n_n = Q_v/(t_n - v),$$

where t_n – is the area of one nozzle opening, m^2;
v – is the air jet exit velocity, m/s.

Foam separation is a type of pneumatic flotation. It differs from other flotation methods in that the wastewater to be treated is fed into the flotation unit from above onto a foam layer already formed as a result of air bubbling. Floated contamination particles are retained in the foam, with both hydrophobic and hydrophilic particles being retained. A stream of finely dispersed air moves towards the purified liquid, creating a foam layer that ensures the necessary duration of stay of contamination particles in the foam for the formation of flotation complexes. When they enter the foam layer, the contaminant particles are fixed not only on the surface of the air bubbles, but also on the surface of the hydrophobic particles that have already been fixed on the air bubbles. As a result, a developed foam surface is created, which reduces the duration of flotation. In these installations, compared to impeller-type flotation machines, there are no centrifugal forces capable of destroying already formed flotation complexes. In addition, in foam separation machines, flotation complexes overcome a water layer only 0.4 m thick when rising to the surface, while in impeller and pressure machines, they overcome a layer 1.5 m thick, which can also cause their partial destruction.

Air is supplied to the liquid by an air blower. Special perforated rubber tubes assembled into cassettes are used as aerators. The tubes are arranged in two rows along the height. Their operating costs are more than twice lower than those of impeller machines. Two-chamber installations are more common. The separation time in one chamber is 3.5 minutes, in two chambers – 7 minutes, with a wastewater flow rate of 60 m^3/s, an air flow rate of 6 m^3 per m^3 of wastewater, and an aeration intensity of 1.34 m^3/hour. The air pressure in the aerator tubes is maintained at 0.045 MPa, and the flotation concentrate flow rate is 12% of the water flow rate. The purification effect of fatty wastewater for ether-soluble substances was 97.2%, and for suspended solids – 97%.

In the fishing industry, pressure flotation machines are mostly used, less often impeller flotation machines. Sometimes only part of the water (but not less

than 50%) is fed through the pressure tank, which is then mixed with the rest of the effluent in a mixer before the discharge chamber, designed to hold the entire effluent for 30 – 60 seconds. Sometimes, to avoid clogging of pipes and fittings, 10 – 20% of purified water is used for saturation.

Electroflotation. The essence of the electroflotation method of wastewater treatment is to transfer polluting particles from the liquid to its surface using gas bubbles formed during the electrolysis of wastewater. Electroflotation is carried out by passing a constant electric current through the water. During the electrolysis of water, hydrogen is released at the cathode and oxygen at the anode. When passing through a cell, 3600 coulombs of electricity decompose 0.3293 g of water, releasing 0.0366 g (0.41 dm) of hydrogen and 0.2927 g (0.205 dm^3 of oxygen.

The bubbles released at the cathode play a major role in the particle flotation process. The current density at the cathode is usually 100–300 A/m^2. Gas bubbles form on the surface of the electrode, grow, and detach from the surface after reaching a certain diameter. The formation of bubbles on the electrodes, as during the boiling of liquids, occurs at certain points – gas formation centres (protrusions, roughness, etc.).

The size of the bubbles that break away from the electrode surface depends not only on the wetting angle, but also on the curvature of the electrode surface. Replacing plate cathodes with wire mesh reduces the size of the bubbles and, consequently, increases the efficiency of wastewater treatment.

As the wire thickness increases, the size of the bubbles increases. The size of hydrogen bubbles released on a copper and stainless steel wire cathode (0.2–1.5 mm in diameter) increases from 17–62 to 120–140 μm and more as the thickness of the cathode wire increases.

Thus, the efficiency of the electroflotation process for wastewater treatment depends on the number and size of the bubbles. To obtain the required number of bubbles of a certain size, it is necessary to correctly select the material and diameter of the cathode wire, as well as the current density. By changing the current density, it is possible to vary the degree of saturation of the pulp with bubbles and thus regulate the speed of flotation treatment of water. As the degree of pulp saturation with bubbles increases, the electroflotation rate increases to the optimum value of current density (200–260 A/m^2) and gas content of 0.1%. A further increase in gas content does not accelerate the flotation process due to the formation of currents in the pulp, which cause the bubbles to detach from the suspended particles. The optimal current density during water purification from grease is 100–150 A/m^2, which corresponds to a degree of water saturation with hydrogen bubbles equal to 0.05%.

The atomic oxygen released at the anode leads to the oxidation of organic substances and, accordingly, to a reduction in the COD and BOC values of wastewater.

The requirements for the anode material are determined by its electrochemical solubility under the action of direct current. An anode made of iron or aluminium is used only in the case of electrocoagulation; in other cases,

either G-4 graphite with a thickness of 20–40 mm or specially treated material – magnetite, lead dioxide – is used. Currently, ORTA anode electrodes are used, which are characterised by greater durability and thinness (1–2 mm) compared to graphite electrodes. They are titanium plates coated with ruthenium and titanium dioxide. Cheaper, but not as durable, are titanium anodes coated with cobalt and manganese oxides.

Cathode materials must meet requirements for corrosion resistance to wastewater and electrolysis products. Energy costs for hydrogen production are also taken into account, as they depend on the electrode material.

With a working water layer height of approximately 1 m in the installation, a current density of 150 A/m^2 , and a temperature of 15–25 ^{0} C, and a pH of 6.5–7.7, electroflotation for 15 minutes allows suspended solids (proteins, fats, carbohydrates) to be removed from wastewater, but the degree of purification is low due to the presence of contaminants in colloidal and dissolved form and amounts to 74% for suspended solids, 80% for fats, 55% for COD, and 90–99% for disinfection.

The presence of salts in wastewater increases the electrical conductivity of water and makes the process more economically viable. Table salt is always present in the wastewater of fish processing enterprises, so its electrolysis occurs simultaneously, resulting in the release of active chlorine. Further chemical reactions produce OCl^- ions and atomic oxygen. Additionally, atomic oxygen is formed during the electrolysis of water. Due to the high oxidising properties of atomic oxygen and OCl^- ions·organic substances are oxidised and wastewater is disinfected. The oxidising processes accompanying electroflotation also explain the reduction in COD of treated wastewater.

An increase in the pH of the medium reduces the cleaning effect. At low pH values, self-coagulation of the smallest particles of contaminants and their enlargement are observed, as a result of which the overall effect increases.

As the chloride concentration increases, the purification effect increases to a limit value of 1200 mg/dm^3. A further increase in concentration leads to the accumulation of active chlorine in the water and the need for further dechlorination of treated wastewater, which complicates the treatment process. Since the wastewater from fish processing plants has a fairly high chloride content, electroflotation treatment of such effluents can be carried out without the addition of chlorides.

A single-chamber electroflotation unit is a four-sided vessel with a bottom at a slight angle to the horizon. Flat sheet electrodes are located at the bottom of the unit. A diaphragm is placed between the electrodes, which reduces the distance between them and, accordingly, lowers the voltage on them. Asbestos fabrics can be used as diaphragm material. The use of such a design with gas separation prevents the formation of an explosive mixture – detonating gas (⅔ hydrogen and ⅓ oxygen) (Fig. 7.24).

The following treatment parameters are recommended: current density – 100 A/m^2, voltage – 8 – 10 V, water column height – 0.5 – 1.0 m, water movement from top to bottom at a speed of 4 m/h in the direction of the electrodes. The

greatest purification effect is achieved with small but highly concentrated effluents. As with flotation, wastewater is practically not freed from colloidal and water-soluble substances of a protein nature.

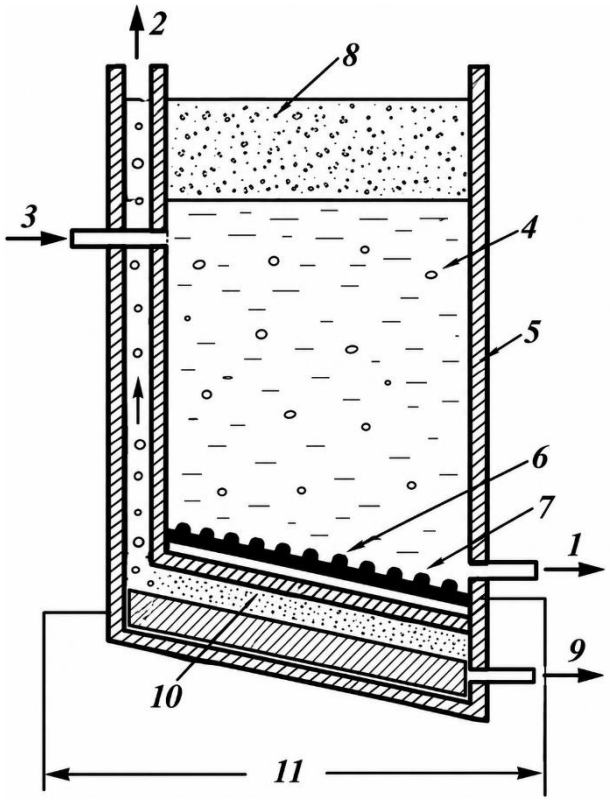


Fig. 7.24. Schematic diagram of a single-cell flotation unit with a diaphragm
1 – wastewater inlet; 2 – oxygen outlet; 3 – foam; 4 – flotation cell; 5 – housing; 6 – cathode; 7 – oxygen discharge channel; 8 – wastewater outlet; 9 – water outlet from the anode chamber; 10 – anode; 11 – diaphragm

The foam (or foam mass) obtained during electroflotation accounts for up to 1.5% of the wastewater flow and has a moisture content of 95–98%. During settling, it breaks down within 15–30 minutes, turning into a flotation concentrate (the upper layer is fat, the middle layer is water with impurities, and the lower layer is sediment). With a throughput capacity of up to 10–15 m^3/hour, the units can be single-chamber, and with a higher throughput capacity, they can be double-chamber.

The advantages of the electroflotation method include: simplicity of design, absence of rotating mechanisms, and the ability to regulate the speed of the process. The disadvantages of the method are the inability to separate colloidal and dissolved organic substances from wastewater and significant energy consumption (up to 0.5 kW•h/m^3).

Electrocoagulation. This is a special case of electroflotation. Electrocoagulation involves passing a direct electric current through wastewater, using metal soluble electrodes, usually iron or aluminium, as the anode. Anodic dissolution of the metal occurs, and ions are transferred to the wastewater. In water, metal ions undergo hydrolysis to form hydroxides, which cause the coagulation of organic substances and colloids formed in the wastewater.

The simultaneous formation of coagulant flocs, flocs of coagulated pollutants and gas bubbles in the limited space of the electrode space creates the conditions for reliable fixation of gas bubbles on the flocs, which ensures the efficiency of the subsequent flotation process of wastewater treatment. The coagulation process can be intensified by anions present in the solution, such as SO_4^{2-}, HCO_3^-, Cl^-, promoting the coagulation of positively charged particles.

Electrocoagulation provides deeper purification of wastewater from suspended and ether-soluble substances than electroflotation. To separate the flocs of coagulant with sorbed contaminants, further settling or flotation is used.

Since electrocoagulation is accompanied by electroflotation, some of the coagulant flocs with sorbed contaminants float up in the form of foam and are removed from the surface into a foam trough (Fig. 7.25).

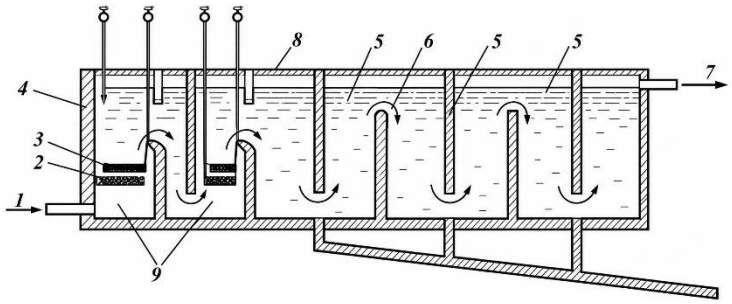


Fig. 7.25. Schematic diagram of a two-stage electrocoagulator with settling chambers:

1 – wastewater inlet; 2 – cathodes; 3 – anodes; 4 – housing; 5 – wastewater clarification chamber; 6 – partitions; 7 – outlet for clarified wastewater; 8 – sludge outlet; 9 – electrocoagulation chambers

Further separation of contaminants is carried out by settling. In this case, the flakes float to the surface of the settling tank, and heavy impurities settle to the bottom. The optimal operating mode of the installation with duralumin electrodes corresponded to a current density on the anode electrodes of 35 A/m^2, a liquid flow time of 3 minutes, and a settling time of 30 minutes. Under these parameters, the purification effect for ether-soluble, suspended substances and COD is (%) – 90, 89 – 91, 60. When treating wastewater with electrodes by electrocoagulation followed by electroflotation of contaminants, the purification effect increases and is respectively (%) – 95.4; 94.9; 71 (Fig. 7.26).

When iron electrodes are used, the purification effect decreases by 30%, but with an increased current density (150 A/m^2), similar results can be obtained. This is because in order to form effective iron hydroxide $Fe(OH)_3$, there must be a sufficient amount of dissolved oxygen in the water. To do this, it is necessary to increase the current density to intensify the process of water hydrolysis.

The foam formed during electrocoagulation is highly stable. During settling, it breaks down after 24 hours. The volume of foam mass when duralumin electrodes are installed is 6% of the wastewater flow, and when iron electrodes are installed, it is 10%. The moisture content of the resulting flotation concentrate is 80% and 90%, respectively.

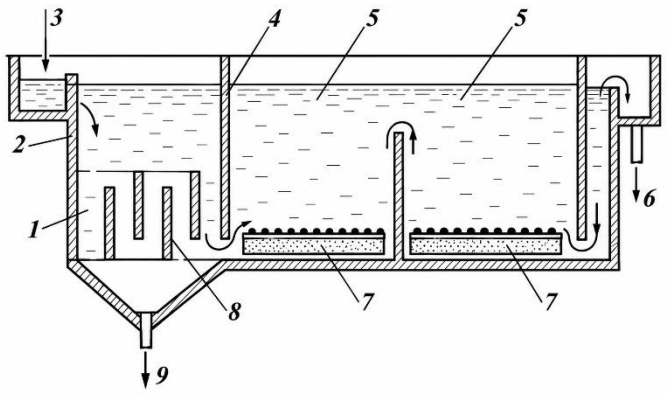


Fig. 7.26. Schematic diagram of an electrocoagulator with a two-section electroflotation chamber

1 – electrocoagulation chamber; 2 – electrocoagulator housing; 3 – wastewater inlet; 4 – partitions; 5 – electroflotation chambers; 6 – clarified water outlet; 7 – insoluble electrode assembly; 8 – soluble electrode assembly; 9 – sludge discharge

During electrocoagulation, water is heated (by 5 ^{0}°C for duralumin electrodes and by 6 ^{0}°C for iron electrodes). The effectiveness of electrocoagulation depends on the presence of chlorides in the solution. A concentration of chlorine ions equal to 800–1000 mg/dm³ can be considered sufficient. The efficiency of the electrocoagulation process depends on the pH of the medium. For duralumin electrodes, the optimal pH is 4.5–7.5, and for iron electrodes, it is above 7. If the pH is less than 4.5, Al^{3+} ions are not completely hydrolysed. At a pH above 7.5, soluble aluminates AlO_2^- are formed. Both of these reduce the cleaning effect. For iron electrodes, at a pH below 7, iron ions are not hydrolysed.

Thus, electrocoagulation is an effective method of treating wastewater from the fishing industry.

The calculation of installations for electroflotation or electroflotocoagulation boils down to determining the total volume of the installation W_i, the volumes of the electrode compartment W_e, and the flotation chamber W_f, hence:

$$W_i = W_e + W_f$$

The volume of the electrode compartment is determined by the possibility of placing the necessary electrode system in it. Thus, when calculating the horizontal arrangement, the width of the section is taken depending on the productivity Q: if Q<90 m³/hour, then B= 2 m, if Q = 90 – 150 m³/hour, then B = 2 – 3 m (Fig. 7.27).

The number of electrode plates n_e in the unit is calculated using the formula:

$$n_e = (B - 2a_1 + a_2)/(\delta + a_2),$$

where a_1 – is the gap between the outer plates and the chamber walls, equal to 100 mm;
a_2 – the gap between the plates, equal to 15–20 mm;
δ – the thickness of the plates, equal to 6–10 mm.

Then the required area of the electrode plates (f_e, m²) will be:

$$f_e = f_{a.e.}/(n_e - 1),$$

where $f_{a.e.}$ –is the active surface area of the electrodes, m²;
$f_{a.e.}$ – is determined by the formula:

$$f_{a.e.} = E \cdot Q/i,$$

where **E** – is the specific electricity consumption, A • h/m³;
Q – is the design wastewater flow rate, m³/h;
i – is the current density on the electrodes, A/m².

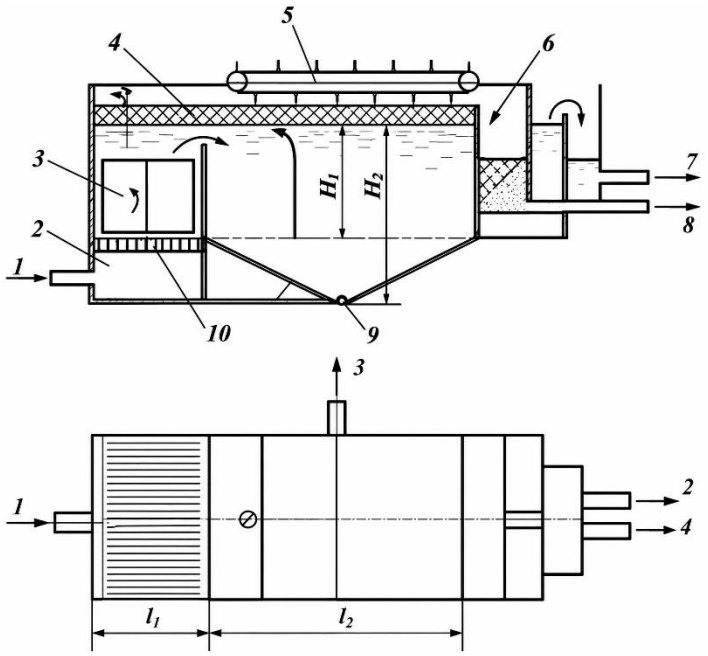


Fig. 7.27. Horizontal electroflotation unit (electrocoagulator)
1 – wastewater inlet; 2 – inlet chamber; 3 – electrode system; 4 – foam; 5 – foam skimming mechanism; 6 – foam collector; 7 – clarified water outlet; 8 – foam mass outlet; 9 – sludge outlet; 10 – settling grid

The values ε and i are determined experimentally. In the treatment of wastewater from many industrial sectors, including the fishing industry, the value of E = 100–600 A•h/m³; i = 50–200 A/m², and the DC voltage is 5–30 V.

After determining f_e and setting the plate height h_e = 1–1.5 m, their length 1_e = fe/he can be found, and then the length of the electrode chamber (L_e, m) can be calculated:

$$L_e = 1_e + 2a_1$$

Then the volume of the electrode chamber (W_e, м^3) will be:

$$W_e = B \cdot H_e \cdot L_e,$$

where H_e –is the working height of the electrode chamber, equal to:

$$H_e = h_1 + h_2 + h_3,$$

where h_1 – is the height of the illuminated layer, equal to 1–1.5 m;
h_2 – is the height of the protective layer, equal to 0.3–0.5 m;
h_3 – is the height of the foam layer, equal to 0.4–0.5 m.

Volume of the flotation chamber:

$$W_f = Q \cdot f_d,$$

f_d – is the duration of flotation, which is determined experimentally and is taken to be 0.3–0.75 hours.

The length L_f and height H_f of the flotation chamber are calculated based on its volume W_f and width B.

During the electroflotation process, it is necessary to determine the amount of electrode metal that has dissolved into the solution, as well as the service life of the electrode system. The amount of metal is determined by the formula:

$$m_e = C_{cd} \cdot E \cdot E,$$

where m_e – is the amount of metal transferred into 1 m³ of solution, g;

C_{cd} –is the current-dependent yield coefficient, equal to 0.5–0.95 (determined experimentally);

E – electrochemical equivalent, g/(A • h), equal to 1.042, 0.695, and 0.336 for Fe^{2+}, Fe^{3+}, and Al^{3+}, respectively.

Service life of the electrode system (t, days):

$$t = \mu \cdot 1000/(m_e \cdot Q_{day}),$$

Q_{day} – is the daily wastewater flow rate, m³/day;

μ – the amount of electrode metal dissolved during electrolysis, kg. μ is calculated using the formula:

$$\mu = d \cdot C_e \cdot f_e \cdot \delta_e \cdot n_e,$$

where **d** – the density of the electrode metal, kg/m³;
Ce – electrode material utilization coefficient, equal to 0.8–0.9.

Electroflotation. Electroflotation consists of treating wastewater using a combined method that includes electrocoagulation and electroflotation. This treatment method is incorporated into the design of the EFU-U unit (Fig. 7.28).

The unit is a three-chamber tank with a total volume of 2 m³ and a wastewater throughput capacity of 8 m³/hour. *The first chamber* (electroflotation unit) is equipped with insoluble electrodes – vertically mounted plates made of X18H9T stainless steel and G-4 graphite. *The second chamber* is an electrocoagulator. It is equipped with soluble electrodes made of vertically mounted D-16A duralumin plates. To collect large settling particles, a triangular prism-shaped pit is installed between the first and second chambers.

The third chamber is an electroflotation unit with horizontally arranged electrodes (graphite plate and stainless steel mesh). In the first chamber, flotation removes the majority of contaminants that float well. In the second chamber, the effluent is coagulated with aluminium hydroxide and, with the help of accompanying flotation, flakes with sorbed contaminants are removed from the water. In the third chamber, final cleaning takes place by flotation of small flakes that did not float in the second chamber. Foam from the surface of the entire installation is collected by a skimmer into a trough. The interelectrode space is 15 mm. The electrode blocks are powered by direct current autonomously for each chamber. Before the wastewater is fed into the installation, it must undergo preliminary mechanical cleaning on screens, in a sand trap and a settling tank.

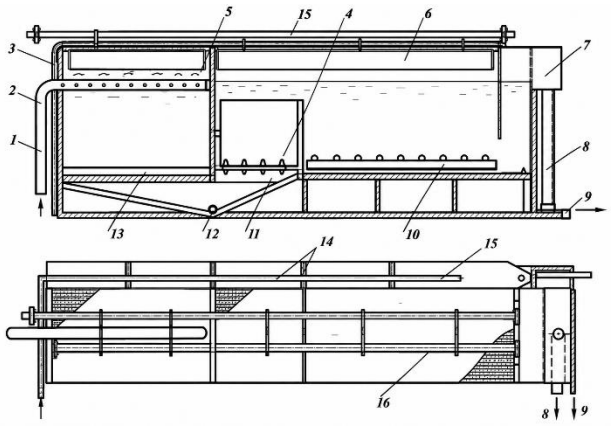


Fig. 7.28. Schematic diagram of an electroflotation coagulation unit (EFK-U)
1 – unit housing; 2 – feed distribution piping; 3 – perforated discharge pipe for directing foam flow through the trough; 4 – partition between chambers; 5 – foam conveyor drive shaft; 6 – foam conveyor scrapers; 7 – **outlet drain at the plant's discharge; 8 –** clarified water outlet; 9 – foam outlet; 10 – electronic unit of the third electroflotation chamber (graphite anode, stainless steel mesh cathode); 11 – electrode unit of the second electrocoagulation chamber (duralumin anodes and cathodes); 12 – sludge discharge; 13 – electrode assembly of the first electroflotation chamber (graphite anodes, stainless steel cathodes); 14 – foam trough; 15 – chains for securing the skimmer blades; 16 – driven shaft of the skimmer

It has been established that the efficiency of such a unit and its energy performance mainly depend on the current density in the electrocoagulation chamber and the duration of water stay in the apparatus. By changing the current density in the second chamber and the total duration of wastewater treatment at the unit (t_0), it is possible to regulate the degree of wastewater treatment.

For maximum wastewater treatment requirements, the following optimal operating mode is recommended: i_1 =5 μA/cm^2; i_2 = 2.5 μA/cm^2; i_3 = 15 μA/cm^2; t_0 = 15 min, in particular t_1 = 3 min, t_2 = 5 min, t_3 = 7 min, where i_1, i_2, i_3 – current density; $t_{(1)}$,$t_{(2)}$,$t_{(3)}$ – the time spent by wastewater in the first, second and third chambers, respectively. In this case, the purification effect for ether-soluble substances can reach 95–99%, for suspended substances – 93–98%, and for COD – 75%.

Electricity consumption is 0.6 kW•h/m^3, duralumin consumption is 8 g/m^3 and depends on the current density and the duration of water treatment. Specific electricity and metal consumption are calculated using the following formulas:

$$W_e = I \cdot U/(1000 \cdot Q \cdot \eta),$$
$$q = K_o \cdot A/Q,$$

where W_e – is the specific electricity consumption, kW•h/m^3;

I – current, A;

U – voltage, V;

Q – wastewater flow, m^3/hour;

η – efficiency of the rectifier;

q – specific metal consumption, g/m³

K_o – metal output per current;

A – electrochemical equivalent of metal, g/(A•h), equal to 0.3359 for aluminium and 0.6949 for trivalent iron.

To determine the actual metal output by current, taking into account the chemical composition of wastewater, the following formulas are proposed for duralumin and iron electrodes, respectively:

$$K_v = 0.015\ pH + 0.044i + 0.0825\ [Cl^-] + 0.644,$$
$$K_v = 0.016\ pH + 0.14i + 0.07\ [Cl^-] + 0.674$$

Dimension: [Cl$^-$] – g/dm^3; density – μA/cm^2. These formulas are valid for pH >5; these formulas are valid for pH >5; [Cl$^-$]>0.3 g/dm^3 and I < 7.5 μA/cm^2.

The majority of contaminants (55% of ether-soluble and suspended substances, 42% of COD) are retained in the first chamber. In the second chamber, the purification effect increases to 80–90%. If the third chamber is replaced with a settling tank designed for 30 minutes, the result is similar to that of electrophloation.

Electroflotation coagulation treatment of wastewater also provides a sanitary and microbiological effect. In treated water, the amount of saprophytic microflora is reduced by 96–99%, and the coli index by 90–99%.

The amount of foam formed during wastewater treatment depends on the current density and the duration of treatment.

It can be calculated using the empirical formula:

$$P = (0.028\, i_1 + 0.41 i_2 + 0.014 i_3) \cdot t_0,$$

where P – is the amount of foam, % of wastewater flow;

i_1 – current density on the anode electrodes of the first chamber, converted to the horizontal area of the chamber, μA/cm^2.

The formula is correct for the ratio $t_1:t_2:t_3$ – 1:0.6:1.4.

On average, under optimal operating conditions, the amount of foam can reach 3.88%, and the flotation concentrate – 1.16% of the wastewater flow.

During electrocoagulation, very stable foam is produced, which completely breaks down after 25–30 hours. If a mixer with two rows of blades on a vertical shaft with a rotation frequency of 30–40 min^{-1}is used, the foam completely breaks down after 15–30 hours.

The following process parameters are used in the calculation:

C_0, Ct_1, Ct_2, Ct – concentration of contaminants in the form of ether-soluble and suspended substances in the initial wastewater after the first and second chambers of the unit and at the outlet of the unit, mg/dm^3;

i_{1g}, i_2, i_3,– current density in the chambers of the installation, where i_{1g} – current density in the first chamber in terms of the horizontal area of the chamber, μA/cm^2;

t_1, t_2, t_3 – duration of water treatment in the chamber, min.

It is recommended to take the width of the device as 0.8–1.0 m for its productivity of 10 m³/hour, 1.5–1.0 m for up to 20 m³/hour, and 3.0–5.5 m for up to 50 m³/hour; current density on the electrodes: $i_{1g} = i_3 = 100–150$ A/m²; $i_2 = 50–75$ A/m^2; ratio of wastewater treatment duration in chambers – $t_1:t_2:t_3$ – 1:0.6:1.4; specific amount of electricity in the second chamber:

i_2 A/m^2	5	15	25	35	5	75
K_e A•year/m^2	6.75	20.25	33.75	47.25	67.50	100.25

7.3. Biological treatment of industrial wastewater

This method allows wastewater to be purified of many organic impurities. The process is natural in nature and is similar to the processes that occur in a reservoir, treatment facilities, or in a glass for determining BOC.

The simplest criterion for assessing the biological oxidisability of organic substances is the experimental determination of BOC. If the BOC value is determined, i.e. oxygen consumption has occurred, then the substance is relatively oxidisable; if no oxygen consumption occurs within 5 days, then it is not oxidisable.

Biological oxidation is carried out by a community of microorganisms (biocenosis), which includes many different bacteria, microscopic fungi, algae, and protozoa. The main role in this community belongs to bacteria, the number of which varies from 10^6 to 10^{12} cells per 1 g of dry biomass.

Among the bacteria in treatment facilities, there are heterotrophs and autotrophs. They differ in their relationship to the source of carbon nutrition. Heterotrophs use ready-made organic compounds as a source of carbon, and process them to obtain energy and biosynthesise cell substances. Autotrophs consume inorganic carbon for the synthesis of cell substances and obtain energy through photosynthesis (using light energy) or chemosynthesis by oxidising certain inorganic compounds (e.g. ammonia, nitrites, divalent iron salts, hydrogen sulphide, etc.).

The more branched the carbon chain, the slower the oxidation. Lower organic acids with up to 10 carbon atoms are easily oxidised, and then microorganisms need a longer adaptation period. Primary alcohols oxidise faster than secondary ones, and secondary ones faster than tertiary ones. Cyclic hydrocarbons oxidise more slowly than paraffinic ones.

However, there are compounds (steroids, alkaloids, terpenoids, adamantanes) that have a more complex structure than monocyclic ones, which oxidise easily and can be oxidised completely. 1,2-dichloroethane, sometimes used in the fishing industry, does not oxidise. Many surface-active substances are not biologically oxidised. Sometimes biological treatment does not result in complete oxidation, and substances that are more undesirable for the water body than the original ones may appear. Therefore, wastewater must be thoroughly investigated, in particular for the oxidising capacity of the substances present in it.

The mechanism of biological oxidation in aerobic conditions by heterotrophic bacteria can be represented as follows:

$$\text{organic substances} + O_2 + N + P \rightarrow \text{microorganisms} + CO_2 + H_2O + \text{biologically non-oxidizable soluble substances}$$

The reaction symbolises the oxidation of the initial organic matter in wastewater and the formation of new biomass.

Biologically non-oxidizable substances remain in the treated wastewater, mainly in a dissolved state, because colloidal and non-oxidizable substances are removed from the wastewater by sorption on activated sludge.

The process of endogenous oxidation of cellular matter, which occurs after the use of an external food source, is described by the following reaction:

$$\text{microorganisms} + O_2 \rightarrow CO_2 + H_2O + N + P + \text{biologically non-degradable part of cell matter}$$

An example of oxidation by autotrophs is the process of nitrification:

$$55NH_4^- + 5CO_2 + 76H_2O \rightarrow C_5H_7NO_2 + 54NO_2^- + 52H_2O + 109H^+$$
$$400NO_2^- + 5CO_2 + NH_4 + 195O_2 + 2H_2O \rightarrow C_5H_7NO_2 + 400NO_3^- + H^+,$$

where $C_5H_7NO_2$ – symbol of the composition of organic matter formed by microorganism cells. The first reaction is carried out by bacteria of the genus *Nitrosomonas,* which convert nitrogen from ammonium salts into nitrate nitrogen, while the second reaction, the oxidation of nitrite nitrogen into nitrate nitrogen, is carried out by bacteria of the genus *Nitrobacter.*

The anaerobic process of methane fermentation occurs according to the following scheme:

$$\text{organic substances} + H_2O \rightarrow CH_4 + CO_2 + C_5H_7NO_2 + NH_4^+ + HCO_3^-.$$

The anaerobic denitrification process occurs in two stages:

$$NO_3^- + \text{organic matter} \rightarrow NO_2^- + CO_2 + H_2O$$
$$NO_2^- + \text{organic matter} \rightarrow N_2 + CO_2 + H_2O + OH^-$$

If the denitrification process is carried out with biologically purified water, practically free of organic matter, then relatively inexpensive methyl alcohol is used as a carbon source. In this case, the total denitrification reaction can be written as follows:

$$6NO_3^- + \mathbf{5H_3COH} \rightarrow 3N_2 + \mathbf{5CO_2 + 7H_2O + 6OH^-}$$

The above diagrams do not cover all the possibilities of biological oxidation, but they are the most common in industrial wastewater treatment.

If the group of microorganisms includes protozoa *(sarcodina, flagellates, ciliates)*, their role is primarily to regulate the number of bacteria in the group of microorganisms and to directly remove large particles of initial impurities from wastewater. Among other associated organisms, rotifers occupy an important place – microscopic animals 0.01–2.5 mm long that feed on bacteria, protozoa, and organic detritus. They are sensitive to oxygen and are a good indicator of the treatment system. In addition, fungi *(yeast, mould)* develop in the biofilm. This entire community is called *activated sludge,* which is used for biological treatment.

7.3.1. The influence of various factors on the effectiveness of biological treatment

The effectiveness of biological treatment processes depends on many factors, most of which are subject to change and regulation within wide ranges within the biological system. The main factors that determine the throughput capacity of the system and the degree of wastewater treatment are described below.

Temperature. The optimal temperature for aerobic processes occurring in treatment facilities is considered to be 29–30°^{0}C, at which the biocenosis is represented by the most diverse and well-developed microorganisms. At the same time, the temperature optimum for different groups of bacteria varies widely: for *psychrophiles* – 10–15 ^{0}°C, *mesophiles* – 25–37 ^{0}°C, *thermophiles* – 50–60 ^{0}C. Microorganisms develop well at optimal temperatures and remain viable when temperatures fluctuate within significant ranges. Thus, psychrophiles can exist within a temperature range of minus 8 to plus 30 ^{0}°C, mesophiles – from 5 to 50 ^{0}°C, and thermophiles – from 20 to 80 ^{0}°C.

If the temperature regime is not optimal, the growth of the culture and the rate of metabolic processes in the cells decrease. The most unfavourable effect on the development of the culture is caused by a sharp change in temperature, accompanied by a change in oxygen solubility. ***Nitrifying*** bacteria are very sensitive to temperature***, and*** their highest activity is observed at temperatures not lower than 25 ^{0}°C.

Active reaction of the environment. The concentration of hydrogen ions (pH) significantly affects the development of microorganisms. Most bacteria develop best in a neutral or near-neutral environment. However, there are microorganisms that develop well in an acidic environment with a pH of 4–6 (micromycetes, yeasts) or, conversely, in a slightly alkaline environment (vibrios).

Biological purification is most effective when the pH value does not exceed 5–9, with a pH of 6.5–7.5 considered optimal. Deviations in pH beyond the range of 5–9 lead to a decrease in the rate of oxidation due to a slowdown in metabolic processes in the cell and a disruption in the permeability of its cytoplasmic membrane. Microorganisms are capable of regulating the pH of the environment themselves, albeit within limited limits. If the temperature and pH values exceed the permissible limits, these parameters must be adjusted in the wastewater entering the biological treatment process.

Biogenic elements. For the normal process of cell substance synthesis and, consequently, for the effective process of wastewater treatment, there must be a sufficient concentration of all the main nutrients in the environment – organic carbon (BOC), nitrogen, phosphorus. In addition to the main elements of cell composition (carbon, nitrogen, oxygen, hydrogen), small amounts of other components are necessary for its construction: manganese, copper, zinc, molybdenum, selenium, magnesium, cobalt, calcium, sodium, potassium, iron, carbonate ion. The content of these substances in natural waters is usually sufficient. Sometimes there is a shortage of nitrogen and phosphorus, and they are added in the form of superphosphate, orthophosphoric acid, ammophos, urea, etc. The sufficiency of nutrients for bacteria in wastewater is determined by the BOC:N:P ratio, which must be at least 100:5:1.

Nutrient level. The nutrient level is taken as the daily pollution load per 1 m^3 of the treatment plant per 1 g of dry biomass or per 1 g of ash-free biomass. Most often, BOC load values are used, and sometimes the load value for individual types of pollution. The classic system (with a load of 150–400 mg BOC_{full} per 1 g of ash-free sludge per day) provides a high degree of BOC purification,

sometimes partial nitrification, has sludge that flocculates well and is populated by a large number of microorganisms of various groups.

Oxygen regime. In aerobic biological systems, the air supply must ensure a constant presence of dissolved oxygen in the mixture of not less than 2 mg/dm^3, to prevent sludge from remaining in anaerobic conditions during its separation from water in secondary clarifiers, where dissolved oxygen is lost at a rate of 1 to 2 mg/dm^3. The aeration system also ensures that the sludge is constantly kept in a suspended state.

Toxic substances. Organic and inorganic substances can have a toxic effect on biological processes. Most substances have one effect or another depending on their concentration in the treated wastewater. In this regard, one of the main tasks is to establish MPC values for individual chemicals, as well as to identify the possible effects of mixtures of substances simultaneously present in the treated wastewater. The MPC is taken as the maximum concentration of a toxic substance present in water that does not have a noticeable negative effect on the operation of biological treatment facilities (MPC). In addition to this value, the MPC_B is sometimes indicated – the concentration of a substance, an increase in which may have a negative effect on the biological oxidation process and on the vital activity of cells.

7.3.2 Methods of biological wastewater treatment in natural conditions

Soil treatment facilities. Soil is a complex mixture of organic and inorganic substances, inhabited by a large number of different microorganisms. The number of bacteria in 1 g of soil is estimated at hundreds of millions. Soil does not provide favourable conditions for the development of pathogenic microflora that parasitises the human body, therefore soil is a powerful factor in the neutralisation of wastewater. Wastewater with a salinity level of up to 300 mg/dm^3 is considered suitable for all agricultural crops. With a salt content of 400–600 mg/dm^3, wastewater can only be used on soils with a good structure, and at concentrations above 600 mg/dm^3, the use of wastewater for irrigation is extremely limited. The wastewater from fish processing plants contains up to 1000–1200 mg/dm^3 of table salt, which makes its use for field irrigation problematic.

Several types of irrigation systems are used: continuous flooding, flooding along furrows and strips, sprinkling and sub-soil irrigation. Sub-soil irrigation is considered the best, as it best meets epidemiological, sanitary, technical, agro-economic and aesthetic requirements. Overloading the soil with wastewater should be avoided, and water should be directed for these purposes after mechanical treatment.

Biological ponds. Biological ponds are artificially created reservoirs in which natural processes are used to treat wastewater. After thorough physical and chemical treatment, wastewater from fish processing plants can be treated in biological ponds to a quality that corresponds to complete biological treatment, i.e. to a concentration of suspended solids of 12–20 mg/dm^3 and BOC_{total} 15–20

mg/dm^3. Increasing the water temperature, artificial aeration, and mixing help to intensify the treatment processes. During treatment in biological ponds, wastewater is disinfected. Bacterial contamination is reduced by 86.9–99.4% in terms of microbial count and by 91.2–99.95% in terms of coli index. In addition, the amount of biogenic elements – nitrogen and phosphorus salts – is reduced.

The ponds operate at water temperatures ranging from +4 to +35 ^{0}°C. The ponds must be preceded by sedimentation tanks. The ponds should be located preferably in areas with poorly filtering soils. The design of the ponds must allow for their periodic cleaning.

Fish and biological ponds can be used to treat wastewater containing organic substances from agricultural production in various sectors of the food industry.

There are ponds with natural and artificial aeration. The most effective oxidation processes in ponds occur in the summer. For better water heating and clarification, ponds with natural aeration are made about 1 m deep. In the case of mechanical aeration, the depth of the pond is increased to 3 m.

Ponds are constructed as single-stage and multi-stage, with several parallel cascades (up to three to five, but not less than two) to avoid the formation of anaerobic bottom zones. The use of multi-stage ponds improves the structure of the fluid flow, eliminates the possibility of untreated wastewater passing through the structure, and thereby increases the efficiency and productivity of the ponds (Fig. 7.29).

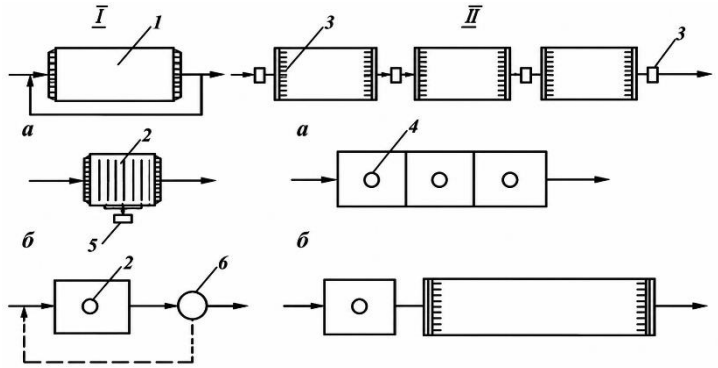


Fig. 7.29. Schematic diagram of the operation of tanks with natural and artificial aeration
I – single-stage tanks: a – with natural aeration and water recirculation; b – with artificial pneumatic aeration; c – with artificial mechanical aeration and recirculation of activated sludge.
II – multi-stage ponds: a – with natural aeration; b – with artificial aeration; c – mixed type.
1 – biological pond with natural aeration; 2 – biological pond with artificial aeration;
3 – overflow aerators; 4 – mechanical aerator; 5 – air blower station; 6 – secondary clarifier

The ponds are aerated using pneumatic or mechanical systems 2b and 2c; in the ponds, mechanical aerators are mounted on pontoons to accommodate fluctuations in the water level. Multi-stage biological ponds can be constructed with a mixed aeration system IIb. For example, the first stage of biological ponds, where the main removal of pollutants takes place, is equipped with artificial aeration, whilst the second stage uses natural aeration.

Four-stage ponds are considered the most effective, in which three stages are designed to retain wastewater for 15 days, and the fourth for one day. The first

two stages involve aeration, the third is without aeration, and in the fourth, lower crustaceans (daphnia) are bred, for which single-celled algae serve as food. Typically, the total BOC_{total} of the water leaving the final stage of the ponds is around 5–7 mg/dm³. It is recommended that water from the final stage be discharged into a water body via an intermediate basin containing aquatic vegetation – reeds, cattails, and bulrushes – which aids in the further purification of the wastewater.

Biological ponds should be located in areas with poorly filtering soils (clay, loam), on land unsuitable for agricultural use. The most appropriate shape for ponds is rectangular, with a length to width ratio of 2:1 to 3:1. Wastewater should be discharged and admitted from opposite ends of the pond. The disadvantages of such structures include low oxidation capacity, seasonal operation, and the need for large areas. This method of treatment is currently only used in fish farming.

Irrigation fields are specially designated land plots for the biological treatment of wastewater in natural conditions with the simultaneous use of moisture and nutrients for growing agricultural crops (Fig. 7.30). Irrigation fields can be communal or agricultural. Products grown on irrigation fields must be tested in a laboratory before consumption.



Fig. 7.30. Irrigation fields for growing agricultural crops [52]

Filtration fields are intended exclusively for biological treatment of wastewater without growing agricultural crops.

The essence of the biological treatment process is that during filtration through the soil in the upper layer, suspended and colloidal substances are adsorbed on the surface of its parts, which over time form a microbial film in the soil pores. The microbes in this film, in the presence of oxygen from the air that penetrates through the pores, oxidise the organic substances present in the wastewater. In order to improve the treatment process, the wastewater is first clarified in settling tanks, during which up to 80% of helminth eggs are removed from the liquid.

The irrigation network of fields can be:

- permanent (main and distribution pipelines);
- temporary (portable pipelines, temporary irrigators);
- irrigation (furrows, strips, etc.).

Pipelines of the permanent network are laid at a depth of 0.7 – 1.2 m from the ground surface. For irrigation fields, open areas of land with a calm terrain and water-permeable soils (sandy, sandy loam, light loam, etc.) should be selected. Wastewater directed to filtration fields is also settled in settling tanks to prevent soil silting.

Filtration fields are ploughed at least twice a year to keep the soil loose.

A hydroponic lagoon **is** an artificial river or pond used to further treat wastewater to acceptable levels by mimicking the self-purification processes that occur in natural water bodies (Fig. 7.31).



Fig. 7.31. Hydroponic lagoon [51]

In lagoons with a depth of 0.9–1.5 m, aeration occurs due to oxygen in the air. The process of oxidation of organic substances is intensified by strong winds or the use of special aerators. Within 1–1.5 years, 70% of the initial mass of organic substances is absorbed by aerobic microorganisms. The oxidation of organic substances is activated when the temperature of the external environment increases.

7.3.3. Methods of biological wastewater treatment in artificial conditions

All biological treatment facilities should be divided into groups according to the location of active biomass in them:

- when the active biomass is fixed on immovable material, and the wastewater slides in a thin layer over the loading material;
- when the active biomass is in the water in a free (suspended) state;

⮟ when both biomass location options are combined.

The first group of structures consists of biofilters, the second – aerotanks and oxy-tanks, and the third – submerged biofilters, biotanks, and aerotanks with fillers.

The most important factors in the formation of sludge biocenoses in treatment plants are the composition of the treated water and the load on the sludge (biofilm). The action of other factors (temperature, mixing, dissolved oxygen concentration) does not significantly change the qualitative composition of the sludge, but it does affect the qualitative state of various groups of microorganisms.

The bacterial population of sludge is represented by the genera *Pseudomonas, Bacillus, Corynebacterium, Arthrobacter, Mycobacterium, Micrococcus, Sarcina, Actinomyces* and others. The biocenoses of treatment facilities include representatives of three classes of protozoa: *Sarcodina*, *Mastigophora* and *Infusoria*. Protozoa are indicators of the state of the oxidation system and the quality of water treatment. In good quality sludge, there are 10–16 species of protozoa per 10^{16} bacterial cells, in medium quality sludge – 5–9, and in poor quality sludge – 1–4. This indicator of sludge composition is called the protozoan coefficient $K_{(PR)}$. In addition, rotifers (*Rotatoria)*, water fungi, oligochaetes, nematodes, and even water mites, insect larvae, and flies (*Psichoda)* develop in sludge and biofilm.

An important property of active sludge is its ability to settle. Poor sludge settleability leads to increased carryover with treated water and, consequently, deterioration in the quality of treatment. Sludge settleability depends on the ability of bacteria to form zoogels – clusters of bacteria covered with a mucous layer.

Sludge has the ability to swell. Swollen sludge is very difficult to separate from water, but thanks to its developed surface of contact with impurities contained in water, it has a high cleaning capacity. Sludge swelling is caused by several reasons and is associated with changes in the operating conditions of the system.

Biofilters. The use of biological filters for the treatment of wastewater from the processing industry requires thorough pre-treatment to remove fats and suspended solids.

The processes that occur in biological filters can be defined as the oxidation of wastewater contaminants with atmospheric oxygen. The processes occur with the participation of microorganisms that form a biological film on the surface of the material – the filter filler.

The essence of these processes is the direct enzymatic oxidation of organic substances contained in wastewater, as well as the synthesis of microorganism cells. e for the filter to work is to ensure contact between the wastewater and the biological film and the presence of the necessary air flow through the filter layer. The course of the biological process in biofilters largely depends on the design features of these structures. These features determine the specifics of hydrodynamic processes, and therefore the nature and speed of the supply of organic substances and oxygen from the air to the cells of microorganisms in the biological film, the removal of the products of biochemical reactions from them,

which in turn affects the speed of the wastewater treatment process and the efficiency of the treatment facilities.

The most important component of a biofilter is the loading material. The loading of a biofilter is characterised by the following main parameters: layer height, specific surface area, porosity and loading density. The height of the loading layer, or the working height of the biological filter, together with other parameters, determines the duration of wastewater retention in the biological filter.

The specific surface area of the loading material determines the total surface area of the biofilm attached to it and, consequently, the area through which organic pollutants are transferred from the liquid flowing around the loading material to the bacterial cells.

For the wastewater treatment process, it is the surface area of the biofilm that is important, not the total amount of biomass in the loading, because only the outer layer is actively working. Inside, near the surface of the loading, an anaerobic zone is formed, which almost does not participate in the process of removal and oxidation of contaminants. An increase in the amount of biomass reduces the volume of the pore space of the loading, complicates air exchange in the biofilter and the supply of oxygen to microorganisms.

Biological filters are divided into two categories according to the type of loading material: volumetric and flat loading. Flat loading is also volumetric, although the volume it occupies is small. Crushed stone, gravel, slag, expanded clay, coke, and foam glass are used as volumetric loading.

Such material has a porosity of 40–50%, a density of 500–1500 kg/m^3, and a specific surface area of 30–120 m^2/m^3, depending on the size of the fractions. Sheet material (plastic, asbestos cement), soft roll fabrics (plastic film, synthetic material), as well as fill elements (rings, pipe sections, etc.) are used as flat loading.

Sheet material is used in the form of various blocks and cassettes, which are placed in the body of the biofilter; soft roll materials are fixed on frames or freely suspended (Fig. 7.32).

The porosity of flat loading from sheet material is 80–97%, from roll materials – 94–99%, and their backfill elements – 70–90%. The specific surface area of sheet and roll loading is 80–130 m²/m³; backfill – 70–100 m²/m³; the density of sheet loading is 40–100 kg/m$^{3)}$; roll loading – 50–60 kg/m^3; backfill loading – 100–600 kg/m^3.

The use of flat loading simplifies the design of the biological filter and reduces transport and construction and installation costs. Certain types of this loading (e.g. perforated plastic film) are cheaper than bulk loading with natural rocks.

The process of removing contaminants from wastewater in biofilters is carried out under the condition of free flow of wastewater through the loading with a biological film fixed on its surface.

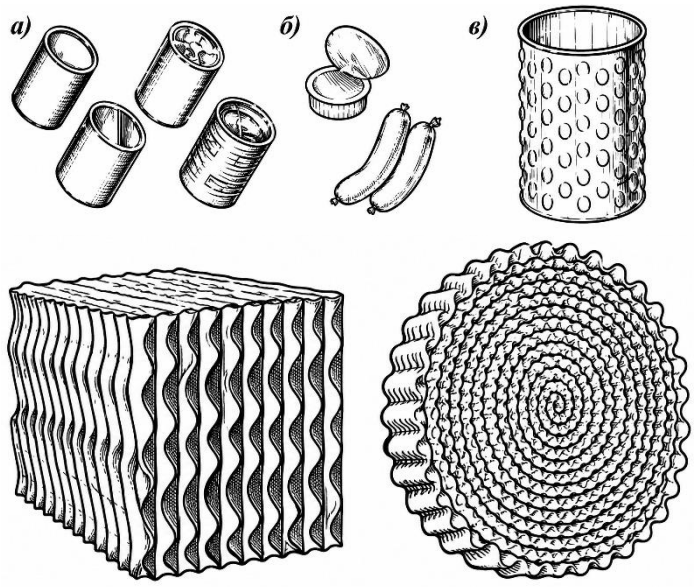


Fig. 7.32. Types of packing

a – Raschig rings; b – rings with a partition; c – rings with a cross-shaped partition; d – Palia rings; e – Berly saddle; f – «Intalox»; g – hollow cylinders with branches; h – sheet metal block packing; i – soft packing

The transfer of contaminants from the flowing wastewater to the surface of the biofilm fixed on the biological filter's loading material is mainly carried out under the action of diffusion forces.

The rate of transfer of contaminants occurs both due to the difference in their concentrations at the liquid-air phase boundary (maximum concentration) and due to the movement of the liquid as it flows through the biological filter media.

In this case, the rate of turbulent diffusion can greatly exceed the rate of molecular diffusion. The oxygen in the air, which is necessary for biological processes, enters the biofilm from the pore space of the biofilter loading.

The transfer and fixation (sorption) of organic substances on the cell surface or in the extracellular space is accompanied by the hydrolysis of complex compounds under the action of various enzymes, as well as by the diffusion of substances through the permeable cell membrane. During intracellular processes, organic substances are oxidised (energy exchange) and new cell material is synthesised (constructive exchange). The oxidation process is accompanied by the release of energy, while the synthesis process consumes energy.

The decomposition products of organic pollutants are removed from the biofilm into the liquid layer and carried away with the liquid flow (dissolved substances) and with the air flow (gaseous substances). At the same time, excess (accumulating) biofilm is washed out by the liquid flow and removed from the biological filter together with the purified water. To separate excess biofilm, purified wastewater after biological filters is settled in secondary clarifiers.

Wastewater with a BOC_{full} concentration of no more than 200–500 mg/dm^3 and under optimal operating conditions, treatment to a residual BOC_{full} of 30–50 mg/dm^3 can be achieved.

The main technological parameters that determine the operating mode of

biological filters are: organic pollutant load, oxidation capacity, hydraulic load on the biological filter, average duration of wastewater flow through the biological filter, recirculation coefficient, and air flow rate.

The organic pollution load is measured by the amount of organic pollution supplied together with wastewater to the biological filter per unit of time and is the main indicator determining the mode and conditions of the biological process. Usually, the specific load according to BOC_{full} is used, referred to 1 m^3 of the biological filter volume:

$$N = \mathbf{La \cdot Q/W},$$

where N – is the specific load according to BOC_{full}, g/(day • m^3);
La – BOC_{full} of initial wastewater, g/m^3;
Q – is the wastewater flow rate, m^3/day;
W – is the volume of the biological filter, m^3.

To compare the operating modes of biological filters, it is more correct to determine the specific load per unit of biofilm surface area or the area of the loading fractions:

$$N_1 = \mathbf{La \cdot Q/}f_{ls},$$

where N_1– specific load, g/(day • m^3);
f_{ls} – loading surface area, m^3.

The oxidation capacity, or productivity of a biological filter in terms of the amount of organic pollutants removed during wastewater treatment, is expressed in grams of BOC_{full} 1m^3 of loading per day:

$$O_c = \mathbf{(La - Lt) \cdot Q/W}$$

where O_c – oxidation capacity, g/(day • m^3);
Lt – BOC_{full} of treated wastewater.

Hydraulic load – the amount of wastewater entering the biological filter, relative to 1 m^2 of the structure's floor space:

$$g = Q/F,$$

where **g** is the hydraulic load, $m^3/(m^2 \cdot day)$;
F – area of the biological filter, m^2.

The average duration of wastewater flow through the biological filter $\mathbf{t_{CP}}$ depends on the hydraulic load, the height of the biological filter, the method of supplying wastewater to the loading surface, the type of loading and the distribution of biofilm in it. The value t_{CP} is an indicator of the duration of the wastewater treatment process in the biological filter. As the hydraulic load increases, the velocity of fluid flow through the biological filter increases and the

flow duration decreases. As the height of the biological filter increases, the duration of wastewater residence in the load increases.

The load, as well as the biofilm attached to it, resist the movement of the flowing liquid, thereby determining the path along which the elements of the liquid flow move, and thus affecting the flow duration.

The recirculation coefficient is the ratio of the recirculation flow rate of the treated liquid to the flow rate of the raw wastewater entering the biological filter:

$$n = Qp/Qt,$$

where n – is the recirculation coefficient;

Qp – is the flow rate of the recirculated liquid, m^3 /day.

Recirculation, i.e. the repeated passage of purified liquid through the biological filter, makes it possible to increase the duration of the purification process, reduce the initial concentration of pollutants in the initial wastewater and increase the hydraulic load, which ensures the flushing of the structure's load during its operation. The recirculation coefficient is determined based on the maximum permissible concentration of pollutants according to BOC_{full} of the mixture of initial and recirculated wastewater, which can be directed to the biological filter without fear of clogging the loading pores as a result of biofilm growth. The recirculation coefficient is determined by the formula:

$$n = (La - Lсм)/(Lсм - Lt),$$

where **Lсм** – is BOC_{full} of the mixture of raw and recycled wastewater, g/m^3.

The amount of oxygen required for the oxidation of organic pollutants in wastewater by biofilm microorganisms must be ensured by supplying the appropriate amount of air to the biological filter. A lack of oxygen slows down the biological process. However, the effect of the amount of air supplied affects the speed of the purification process only until the process is fully supplied with the necessary amount of oxygen. If sufficient air exchange in the pore space of the biological filter load is not provided by natural ventilation, forced air supply is provided.

Design of biological filters. Depending on the technological parameters and type of loading, biological filters are classified as operating in incomplete and complete biological purification modes; for high and low organic pollution loads; without recirculation and with recirculation of purified liquid; with volumetric and flat loading. Biological filters are drip (low-capacity) and high-load (high-capacity). The classification of biological filters is given in Table 7.1.

Drip biofilters are characterised by low load in terms of organic pollution, low hydraulic load, prolonged contact of pollutants with the biological film, and low speed of biochemical processes. Under these conditions, biological filters provide complete biochemical treatment of wastewater with a high degree of nitrification and a slight increase in biomass.

Therefore, drip biofilters can be used with relatively low porosity fillings.

Such biofilters operate with natural ventilation of the filling. The height of drip biofilters is usually 1–2 m. The bulk filling has a particle size of 25–40 mm. In biofilters with high loading, the organic pollution load and the speed of the process are significantly higher than in trickle filters. This necessitates an increase in the hydraulic load, the use of fillings with higher porosity, and the intensification of air exchange in the filling by means of forced ventilation. The particle size of the bulk loading ranges from 40–70 to 100 mm. Increased hydraulic loading due to recirculation allows for the removal of rapidly growing (excess) biological film and prevents silting of the loading.

By increasing the height of the filter (2–4 m or more) and introducing recirculation, the required residence time of wastewater in the load at higher fluid velocities is achieved. High-load biological filters can operate in incomplete and complete biological treatment modes with an initial stage of nitrification. Biological filters are round or rectangular tanks with walls made of precast or monolithic reinforced concrete.

Table 7.1. Classification of biological filters by performance and type of loading material

Biological filter	Loading material	Load characteristics			Load*)
		Porosity, %	Surface development	specific surface area	2 ÷ 4.5 – ...
Drip	Crushed stone, gravel, etc., size 25 – 40 mm	40 – 45	high	30–120	5 ÷ 8 – 0 ÷ 50 10÷20
High-load with volumetric loading	Same, size 40–70 mm	40–60	medium	50 – 80	30–50 10–20
	The same, size 40–100 mm	45 – 55	low	30	… 30 ÷ 50 10 ÷ 20
	Rigid sheet material in the form of vertical rows, grids	90 – 97	average	60 – 80	2 ÷ 8 30 ÷ 50 10 ÷ 20
High-load with flat loading	Corrugated, perforated, rigid and flexible material in blocks or rolls	90 – 99	high	90 – 120	2 ÷ 8 0 ÷ 90 10 ÷ 20
	Filling elements made of rings, pipe scraps	70 – 90	high	70	2 ÷ 8 … 10 ÷ 20

Note: *) – in g BOC_{full} per day per 1 m^2 of the surface of the loading material, low – high (in the numerator), average (in the denominator), m^2/m^3.

Biological filters are circular or rectangular tanks, the walls of which are constructed from precast or monolithic reinforced concrete 2. The biological filter bed 3 is situated on a drainage base 5 consisting of reinforced concrete grating

slabs. The solid monolithic base is equipped with channels for collecting and discharging treated water 6. The inter-base space, at least 0.6 m high, serves to distribute air within the biological filter bed and to flush the base and channels (Fig. 7.33).

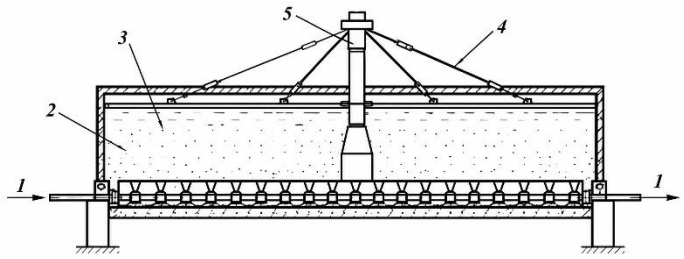


Fig. 7.33. High-load biological filter with a reactive sprinkler
1 – air inlet; 2 – housing; 3 – filter media; 4 – reactive sprinkler;
5 – inter-bed space; 6 – outlet for treated effluent

A window is installed in the walls of the biological filter at the level of the inter-bed space, through which air enters during natural ventilation. The windows are fitted with devices that allow them to be tightly closed during the operation of biological filters with forced ventilation. 1. The biological filters are backfilled with crushed stone, pebbles and other rock materials of 40–70 mm in size, laid uniformly to the required height. The lower support layer of the fill, 0.2 m high, is made of material with a particle size of 70–100 mm. Wastewater is distributed across the surface of circular biofilters, as a rule, by reactive sprinklers 4. The number and diameter of the sprinkler's perforated distribution pipes are determined based on an initial fluid velocity of 0.5–1.0 m/s. The sprinkler pipes are positioned 0.2 m above the bed surface; the fluid head at the sprinkler must be at least 0.5 m.

Rectangular biological filters designed to distribute wastewater across the filter bed are fitted with sprinkler nozzles. The diameter of the sprinkler holes is 18 – 32 mm, with a free head of 0.5–1.5 m. Drip biological filters operate with a periodic inflow of wastewater. For this purpose, they are supplied by dosing tanks with a siphon device. In biological filters with flat loading, where polyethylene, polyvinyl chloride and other plastics of various profiles are used, asbestos sheets are assembled into blocks (Fig. 7.34).

The loading units are manufactured in several types and arranged in such a way as to fill the entire volume of the structure. The walls of biological filters may be constructed from plastic or asbestos sheets mounted on a metal frame, or from reinforced concrete.

Biological filters with plastic media operate with natural ventilation and are usually located in heated rooms.

The disadvantages of plastic block media include the complexity of its manufacture, the difficulty of arranging the blocks within the biological filter, and the high cost. However, it can be used in the dairy, meat and fish industries if film materials are employed, as the cost of such media does not exceed that of bulk media made from natural materials.

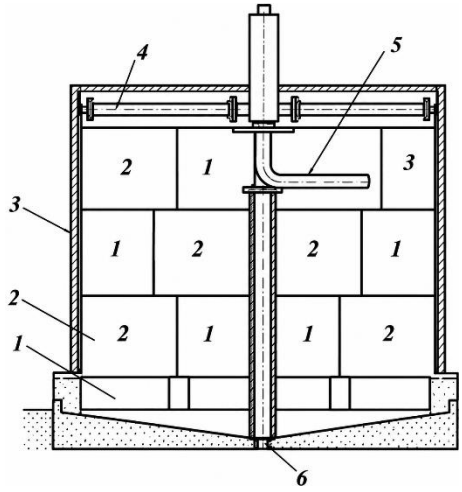


Fig. 7.34. Octagonal biofilter in plan view with plastic media
1 – drainage; 2 – media bed made of corrugated polyethylene sheets: 1, 2, 3, 4;
3 – housing; 4 – spray nozzle; 5 – influent; 6 – effluent

When loading in the form of freely suspended sheets of thin film, the design of biological filters is simplified, which in turn reduces their cost. It has been established that biological filters with flat loading have a much greater oxidation capacity than biofilters with volumetric loading. With a biofilter height of 4 m and a purification degree of 250 to 25 mg/dm^3 according to $BOC_{full,}$ the oxidation capacity is 7–9 BOC_{full} per 1 m^3/day.

Submerged biofilters, or biodiscs (Fig. 7.35), consist of a rotating shaft *9* with discs *3* mounted on it, and a tank *2* containing wastewater, into which the discs are submerged to a depth of one-third to one-half of their diameter. The discs (plates) are made of various materials, preferably lightweight ones (plastics, aluminium alloys, asbestos cement), and are spaced 10–20 mm apart. The gap between the bottom and the discs is 25–50 mm. The number of plates on the shaft can vary from 20 to 200. The diameter of the discs is 0.5–3 m. The average rotational speed of the shaft is approximately 1 rpm.

The water to be treated enters the semi-circular bottom tank *2* via the outlet or overflows 1 over the walls, which are positioned parallel to the discs, allowing all the discs to operate in sequence.

Wastewater flows through the tank at different speeds depending on the desired degree of purification. Typically, the minimum retention time of water in the tank is 70 minutes, and if a higher degree of purification is required, it can reach 3 hours or more. A biofilm up to 4 mm thick builds up on the discs. By alternately submerging in and emerging from the water, the biofilm extracts contaminants and oxidises them using oxygen obtained directly from the atmosphere.

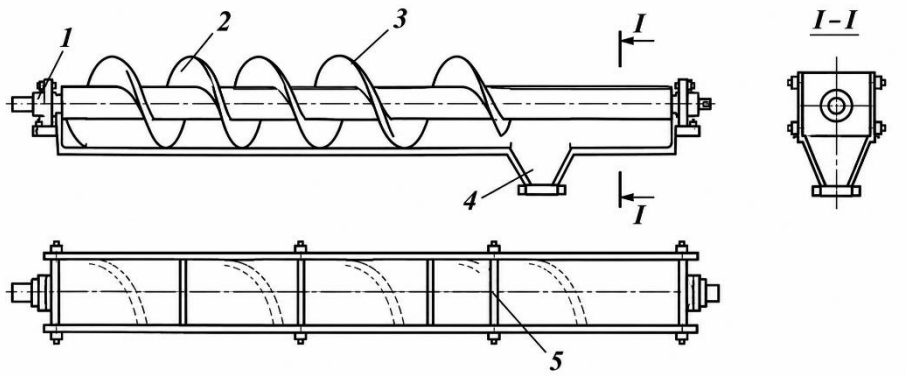


Fig. 7.35. Diagram showing the installation of bio-discs together with sedimentation tanks

1 – effluent discharge chamber; 2 – trough; 3 – biodiscs; 4 – sludge pipe; 5 – clarifier; 6 – treated water discharge chamber; 7 – clarifier; 8 – pipeline with sludge pumping station; 9 – rotating shaft

The dead portion of the biofilm enters the water and is then carried out with the treated water into the secondary clarifier. As the water remains in the tank for a long time, activated sludge forms in it, and its contribution to the overall treatment effect must be taken into account. The wastewater in the tank is aerated by the rotation of the discs, and the combination of rotational and translational movement of the water helps to keep the activated sludge (and all other substances) in suspension.

Submerged filters are often designed as two- or three-stage systems, which allows the biofilm activity in each filter to be enhanced and, furthermore, enables a portion of the effluent to be recirculated to the top of the tank to ensure more thorough removal of pollutants.

Submerged biofilters are designed based on the oxidation capacity per 1 m² of surface area per day. The oxidation capacity is determined experimentally and can range from 7 to 100 g BOC per 1 m² of surface area per day. The use of submerged biofilters is appropriate as primary treatment facilities for treating small volumes of wastewater (up to 1,000 m³/day), followed by advanced treatment in other types of biological oxidisers.

Biofilters of all types can be used at fish processing plants whose sewerage networks are not connected to the municipal sewerage system. They are installed at on-site treatment facilities following pressure flotation or electrocoagulation of the wastewater.

Wastewater treatment in aerotanks (biotanks)

Aerotanks are classified according to the following main characteristics:

By *flow structure* – aerotanks-extruders, aerotanks-mixers and aerotanks with dispersed wastewater discharge.

By *method of activated sludge regeneration* – aerotanks with separate sludge regenerators and aerotanks combined with regenerators.

By *active sludge load* – high-load, normal-load, and low-load.

By *number of stages* – single-stage, two-stage and multi-stage.

By *design* – rectangular, round, combined, etc.

By *type* of *aeration system* – pneumatic, mechanical, pneumatic-mechanical.

There are a great many design variations and technological operating schemes. In displacement aeration tanks with one to four corridors (straight coal tanks), water and sludge are fed at the beginning of the structure, and the mixture is discharged at the end. In mixing aeration tanks, wastewater and sludge are fed and removed evenly along the long sides of the structure, and the mixture is mixed almost instantly. In intermediate-type aeration tanks, either water or sludge can be fed in a concentrated manner, with the mixture being removed in a concentrated manner at the end of the aeration tank.

The transfer of contaminants from wastewater to sludge occurs relatively quickly – in 10–30 minutes, the water can be purified by more than 50% (in terms of BOC) and in 1.5–3 hours, it can be purified almost completely. Contaminants removed by sludge cannot be released back. The oxidation of contaminants obtained by sludge occurs from the very beginning of the purification process, but lasts much longer than the transfer of contaminants from wastewater to sludge and ends after the separation of practically clean water from it, which occurs in sludge regenerators.

In aerotanks, the sludge is kept in a suspended state due to the fact that the water is constantly mixed and enriched with oxygen from the air by means of one or another aeration system. Sometimes, fillers, for example, made of vinyl plastic, are placed in aerotanks. In this case, part of the active sludge remains suspended (as in a conventional aerotank), and part of the sludge in the form of a biofilm covers the surface of the loading. As a result, the total dose of sludge increases and the oxidation capacity of the plant, called a biotank, increases.

Structurally, a biotank is a rectangular metal tank. It is interconnected with a regenerator tank.

For treatment in the biotank, wastewater is fed after preliminary treatment in a pressure flotation unit and piped to a dosing tank, from where it can be directed either to the biotank or to the regulator. From the biotank, wastewater flows through a pipeline into a secondary clarifier. Treated water is discharged through a pipeline. Circulating activated sludge is pumped through a pipeline into a sludge collection tank, from which it can flow into either the biotank or the regenerator.

The aerator consists of a system of slotted vinyl plastic pipes with a diameter of 50 and 32 mm, with 4 mm wide slots located on the underside of the pipes at ⅓ of the diameter. The distance between the pipes is 150 and 100 mm, and between the slots is 20 mm. The aerator is submerged 650 mm below the water surface. Perforated vinyl plastic loading sheets are stretched over metal frames and installed perpendicular to the longitudinal walls of the biotank along its entire length on channel guides with a pitch of 9 cm. The nets are raised and lowered using a hoist with a lifting capacity of 0.5 tonnes. Part of the loading is installed above the aerator along its length, inclined at an angle of 60^0 to the horizon in order to increase the oxidative capacity of the biotank. The secondary sedimentation tank with a diameter of 1.3 m and a height of 5 m has a telescopic central pipe that can be installed at a height of 1.3–3.8 m from the water level in it, which ensures the necessary sedimentation time.

The minimum permissible air flow rate that ensures the critical velocity (0.20–0.25 m/s) of the circulating flow is 24 m^3/m^3• h for an aerotank and 26 $m^3/(m^3 \cdot h)$ for a biotank, since the load has a certain braking effect on the water velocity in the biotank.

To ensure optimal biological treatment, wastewater from fish processing plants is pre-treated to reduce the content of suspended and ether-soluble substances to no more than 300 and 200 mg/dm^3 respectively; COD and BOC_{full} – no more than 3000 and 2000 mgO_2/dm^3 respectively. Aerotanks are best used to an incomplete degree of treatment (treatment effect according to BOC_{full} – 70%), biotanks – to complete (purification effect over 70%) provided that the wastewater flow in aerotanks is up to 500 m^3/day, in biotanks – from 500 m^3/day and above. Daily load according to BOC_{full} at a temperature of 20 ^{0}C and BOC of the treated liquid 20 – 25 mg/dm^3 should be taken for an aerotank up to 740 mg/hour of dry ash-free active sludge, for biotanks a – up to 1350 mg/hour of dry ash-free sludge and biofilm. However, due to the seasonal nature of work at fish processing plants, it is advisable to use biofilters, which are more compact and better tolerate uneven wastewater inflow.

7.3.4. Calculation of technological indicators and basic parameters of treatment facilities

Wastewater treatment plants must compile monthly technological reports on the operation of individual treatment facilities. The report is compiled using data from laboratory logs (qualitative indicators) and workshop logs (quantitative indicators). Table 7.2 shows the formulas used to calculate the main operating parameters of individual treatment facilities for the month.

Table 7.2. Calculation of the main parameters of treatment facilities

No.	Indicator and calculation formula	Symbol
1	Average daily wastewater inflow: $Q_{avg} = \frac{Q}{m}$	Q_{avg} – average daily wastewater inflow, m^3 /day; Q – monthly wastewater inflow, m^3; m – number of days in a month
2	Coefficient of daily unevenness of wastewater inflow: $K_{day} = \frac{Q_{макс}}{Q_{ср}}$	K_{day} – coefficient of daily unevenness; Q_{max} – maximum daily wastewater inflow during the month, m^3 /day
3	Coefficient of hourly unevenness of wastewater inflow: $K_{hour} = \frac{Q_{макс}}{Q_{ср}}$; $q_{avg} = \frac{Q_{макс}}{24}$	K_{hour}– hourly unevenness coefficient; q_{avg} – maximum hourly inflow per day with maximum wastewater inflow, m^3 /hour; Q_{max} – maximum daily inflow, m^3/day; q_{avg} – average hourly inflow per day with maximum wastewater inflow, m^3/hour;
4	Total coefficient of	K_{total}– total unevenness coefficient;

	unevenness of wastewater inflow: $K_{total} = K_{day} \times K_{hour}$	K_{day} – daily unevenness coefficient; K_{hour} – hourly unevenness coefficient
5	Number of working grates (sand traps, sedimentation tanks, etc.): $n = \frac{m_p}{m_{год}}$	n – number of operating grates (sand traps, etc.); m_p – number of hours of operation of all grates (sand traps, etc.) per month; m_{hr} – number of hours in a month
6	Aeration intensity: $I = \frac{D_{год}}{\omega}$; $D_{hour} = \frac{D_м}{m_{год}}$; $\omega = \omega_1 \times n_1 + \omega_2 \times n_2$	I – aeration intensity, m^3/m^2 /hour; D_{hour} – hourly air flow to all sand traps (aerotanks), m^3; ω – total water surface area of operating sand traps (aerotanks), m^2; D_m – air flow rate for all sand traps (aeration tanks) per month, m^3; m_{year} – number of hours in a month; ω_1, ω_2 – water surface area of one sand trap (aeration tank), m^2; n_1, n_2 – number of operating sand traps (aerotanks)
7	Aeration intensity (for structures of the same type and size): $I = \frac{D_1}{\omega_1}$; $D_1 = \frac{D_м}{m_p}$	I – aeration intensity, m^3/m^2 /hour; D_1 – hourly air consumption per sand trap (aeration tank), m^3 /hour; D_m – air flow rate for all sand traps (aeration tanks) per month, m^3; ω_1 – water surface area of one sand trap (aeration tank), m^2; m_p – number of hours of operation of all sand traps (aerotanks) per month
8	Time wastewater stays in sedimentation tanks: $t = \frac{W}{q}$; $W = W_1 \times n_1 + W_2 \times n_2$; $q = \frac{Q}{m_{год}}$	t – wastewater retention time, hours; W – volume of the settling zone of all operating settling tanks, m^3; q – hourly wastewater flow to all settling tanks, m^3/hour; W_1; W_2 – volume of the settling zone of one settling tank, m^3; n_1, n_2 – number of operating sedimentation tanks; Q – wastewater inflow to all settling tanks per month, m^3; m_{hour} – number of hours in a month
9	Time wastewater stays in settling tanks (for structures of the same type and size): $t = \frac{W_1}{q_1}$;	t – time wastewater stays in settling tanks, hours; W_1 – volume of the settling zone of one settling tank, m^3; q_1 – hourly wastewater flow per sedimentation tank, m^3 /hour; m_p – number of hours of operation of all settling

	$q_1 = \frac{Q}{m_p}$	tanks per month; Q – wastewater inflow to all settling tanks per month, m^3
10	Wastewater aeration period: $t = \frac{W}{q}$; $W = W_{1a} \times (n_a + W_{1p} n_p)$; $q_1 = \frac{Q}{m_p}$	t – aeration period, hours; W – volume of aeration tanks and regenerators, m^3; W_{1a} – volume of one aeration tank, m^3; n_a – number of operating aeration tanks; W_{1p} – volume of one regenerator, m^3; n_p – number of regenerators in operation; q – hourly wastewater flow to all aerotanks; Q – monthly wastewater inflow, m^3; m_{hour} – number of hours in a month
11	Average sludge dose: $d_{avg} = \frac{d_{aep} W_a + d_{per} W_p}{W}$; $W = W_a + W_p$; $W_a = W_{1a} \times n_a$; $W_p = W_{1a} \times n_p$	d_{avg} – average dose in structures, g/l; sludge dose in aerotanks, g/l; sludge dose in regenerators, g/l; W_a – volume of operating aeration tanks, m^3; W_p – volume of operating regenerators, m^3; W – total volume of operating aeration tanks and regenerators, m^3
12	Average sludge dose (for the same volume of all aeration tanks and regenerators: $d_{avg} = \frac{d_{aep} \times n_a + d_{per} \times n_p}{n_a + n_p}$	d_{avg} – average sludge dose in structures, g/l; n_a – number of operating aeration tanks
13	Air consumption per 1 kg of BOC_5 removed: $D_{BOC} = \frac{Д_с 1000}{Q_{сер} \times (L_a - L_t)}$ $D_{(day)} = \frac{Д_м}{m}$ $Q_{avg} = \frac{Q}{m}$ or $D_{BSK} = \frac{Д_м \times 1000}{Q \times (L_a - L_t)}$	D_{BOC} – air consumption per 1 kg of BOC_5 removed, m^3; D_{day} – daily air consumption, m^3; Q_{avg} – average daily wastewater inflow, m^3; L_a – BOC_5 of wastewater entering the aeration tanks, g/m^2 ; L_t – BOC_5 of treated wastewater, g/cm^2; D_m – air consumption for all aeration tanks per month; m – number of days in a month; Q – wastewater inflow per month, m^3
14	Air consumption per 1 m^3 of wastewater: $D = \frac{Д_м}{Q}$	D – air consumption per 1 $m^3$of wastewater, m^3; D_m – air consumption for all aeration tanks per month, m^3; Q – wastewater inflow to all aeration tanks per month, m^3
15	Load per 1 m^3 ofaerotank according to BOC_5: $N = Q_{avg} \times L_a \times W$	N – load per 1 m^3 of aeration tank according to BOC_5, g/day; Q_{avg}– average daily wastewater inflow; L_a– BOC_5 of wastewater entering the aeration

		tanks, g/m³; W – total volume of operating aerotanks and regenerators
16	Load per 1 g of ash-free dry matter of sludge: $N_a = \frac{N}{d_{сер} \times (1 - S_л)}$	N_a – load per 1 g of ash-free dry matter of activated sludge, g; N – load per 1 m³of aeration tank according to BOC_5, g/day; d_{avg} – average sludge dose in structures, g/l; S_l – ash content of sludge in fractions of a unit (for example, ash content 25 % S_l =0.25)
17	The load per 1 m³ of the aeration tank and per 1 g of ash-free dry sludge solids is calculated using the formulas given above. Instead of BOC_5 entering the wastewater aeration tanks, the suspended solids content is substituted	
18	The electricity consumption per 1 kg of BOC_5 (kW•h) removed is calculated using the air consumption formula. Instead of air consumption, the electricity consumption, kW•h, is substituted.	
19	Filtration rate: $U_ф = \frac{U_ф}{m_p \bullet f}$	$U_ф$ – filtration rate, m/hour; $Q_ф$ – amount of water (filtrate) supplied to the filters per month, m³; m_p – number of hours of operation of all filters per month; f – area of one filter, m²
20	Flushing intensity: $\frac{I_{пр} - Q_{пр}}{m_{пр} \times f \times 3600}$	$I_{пр}$ – flushing intensity, l/s/m²; Q_{pr} – amount of flushing water per month, litres; m_{pr} – number of flushing hours per month; f – area of one filter, m²
21	Time of one flushing: $t_{(pr)} = \frac{m_{пр} \times 60}{n_{пр}}$	t_{pr} – time of one flush, min; m_{pr} – number of hours of washing per month
22	Filter cycle: $t_{(ф)} = \frac{m_p}{n_{пр}}$	$t_ф$ – filter cycle, hours; m_p – number of hours of operation of all filters per month;

		n_{pr} – number of flushes per month
23	Chlorine dose: $d_{(x)} = \frac{Q_x}{Q}$	d_x – chlorine dose, mg/l; Q_x – chlorine consumption per month, mg Q – amount of chlorinated wastewater, l
24	Amount of ash-free dry substance in the sediment: $Q_{(without)} = \frac{q_0 \times (100 - P_0) \times (1 - S_0)}{100}$	$Q_{ash\text{-}free}$ – ash-free dry matter of sludge, tonnes; q_0 – amount of sludge loaded into methane tanks per month, m³; P_0 – moisture content of the loaded sludge, %; S_0 – ash content of the sediment loaded in fractions of a unit
25	Amount of ash-free dry matter in sludge: $M_{without} = \frac{q_м \times (100 - P_м) \times (1 - S_м)}{100}$	$M_{ash\text{-}free}$ – ash-free dry matter of sludge, t; Q_m – amount of sludge loaded into methane tanks per month, m³; P_m – moisture content of the sludge loaded, %; S_m – ash content of the sludge loaded in fractions of a unit
26	Sediment dose loaded: $d = \frac{(q_0 + q_м) \times 100}{m \times W}$; $W = W_1 \times n_1$	d – daily dose of sludge loaded into methane tanks, %; q_0 – amount of sludge loaded per month, m³; q_m – amount of sludge loaded per month, m³; m – number of days in a month; W – volume of working methane tanks, m³; W_1 – volume of one methane tank, m³; n_1 – number of operating methane tanks
27	Sediment dose loaded per ash-free substance: $d_6 = \frac{(Q_{ash.sub} + M_{ash.sub}) \times 100}{m \times W}$	d_6– dose of sediment loaded per ash-free substance, kg/m³; $Q_{ash.sub}$ – amount of ash-free dry matter in sludge per month, tonnes; $M_{ash.sub}$ – amount of ash-free dry matter of sludge per month, t; m – number of days in a month; W – volume of working methane tanks, m³
28	Amount of gas obtained per 1 kg of ash-free dry matter of sludge: $G_b = \frac{Г}{[(Q_{ash.sub} + M_{ash.sub}) \times 1000]}$	G_b – gas output from 1 kg of ash-free dry sediment, m³; G – amount of gas obtained per month, m³; $Q_{ash.sub}$ – amount of ash-free dry matter of sludge per month, t; $M_{ash.sub}$ – amount of ash-free dry sludge per month, t
29	Percentage of fermentation by gas: $U = \frac{G\gamma_г \times 100}{[(Q_{ash.sub} + M_{ash.sub}) \times 1000]}$	U – percentage of gas fermentation; G – amount of gas obtained per month, m³; γ_g – average density of gas, kg/m³; $Q_{ash.sub}$ – amount of ash-free dry matter in the sludge per month, t; $M_{ash.sub}$ – amount of ash-free dry matter of sludge

		per month, t
30	Percentage of ash-free dry matter in the sludge processed: $U_b = \frac{Q_{\text{ash.sub.fs}} \times 100}{Q_{\text{ash.sub}} + M_{\text{ash.sub}}}$; $Q_{\text{ash.sub.fs}} = \frac{Q_{\text{zb}} \times (100 - P_{\text{zb}}) \times (1 - S_{\text{zb}})}{100}$; $Q_z = q_0 + q_m$	U_b – percentage of processed ash-free dry matter in sludge; $Q_{\text{ash.sub.fs}}$ – amount of ash-free dry matter in fermented sludge per month, t Q_{zb} – amount of sediment (fermented) unloaded from methane tanks per month, m³; P_z – moisture content of unloaded sludge, %; S_z – ash content of unloaded sludge, %; q_0 – amount of sludge loaded per month, m³; q_m – amount of sludge loaded per month, m³; $Q_{\text{ash.sub}}$ – amount of ash-free dry matter of sludge per month, t; $M_{\text{ash.sub}}$ – amount of ash-free dry matter of sludge per month, t
31	Steam consumption per 1 m³ of loaded sediment: $q_{\text{steam}} = \frac{Q_{\text{пар}}}{(q_0 + q_м)}$	q_{steam} – steam consumption per 1 m³ of loaded sludge, kg; Q_{steam} – monthly steam consumption, kg; q_0 – amount of sludge loaded per month, m³; q_m – amount of sludge loaded per month, m³
32	The residence time of the mixture in the fermented sludge compactors is determined by the formulas for sedimentation tanks. Instead of the settling zone of the settling tanks, the total hydraulic volume of the compactors is substituted into the formula, and instead of the wastewater consumption, the amount of incoming sludge mixture and wash water is substituted.	
33	The amount of dry matter in the sludge entering the vacuum filters: $Q_{\text{adm}} = \frac{q_{sf} \times (100 - P_{ms})}{100}$	Q_{adm} – amount of dry matter in the sludge per month, t; q_{sf} – amount of sludge fed to vacuum filters per month, m³; P_{ms} – moisture content of the sludge fed to the vacuum filters, %
34	Vacuum filter productivity in terms of dry matter:	P_f – productivity of vacuum filters in terms of dry matter, kg/m² /hour; m_p – number of hours of operation of all vacuum

	$P_f = \frac{Q_{adm} \times 1000}{m_p \times f}$	filters per month; f – filtration area of one vacuum filter, m^2
35	Chlorinated iron consumption (dose): $d = \frac{A \times 100}{Q_{adm}}$; $A = \frac{q_{cz} \times a}{100}$; or $= \frac{q_{cz} \times a}{Q_{adm}}$	d – chlorinated iron dose, % per dry matter of sediment; A – chlorinated iron content, t; Q_{adm} – amount of dry matter fed to the vacuum filters of the sediment, t; q_{cz} – amount of chlorinated iron consumed per month, t; a – chlorine iron activity ($FeCl_3$ content), %
36	The consumption (dose) of lime, %, per dry matter of sediment is determined by the formulas for chlorinated iron. Instead of ferric chloride, substitute the amount of lime consumed, and instead of ferric chloride activity, substitute lime activity, calculated as CaO.	
37	Amount of thermally dried sediment: $q_{dry} = q_M - W_w$ $W_w = \frac{q_M \times (P_H - P_K)}{100 - P_K}$	q_{dry} – amount of thermally dried sludge, t; q_M – amount of mechanically dewatered sludge fed into the drum dryer per month, t; W_w – amount of moisture evaporated in the dryer, t; P_H – moisture content of mechanically dewatered sludge, %; P_K – moisture content of thermally dried sludge, %
38	Amount of thermally dried sludge: $W_T = \frac{q_{dry}}{\gamma}$	W_T – amount of thermally dried sludge, t; q_{dry} – amount of thermally dried sludge, t; γ – average density of thermally dried sediment
39	Amount of dry matter in mechanically dewatered sludge: $q_{avg} = \frac{q_M \times (100 - P_H)}{100}$	q_{avg} – amount of dry matter in mechanically dewatered sludge, t; q_M – amount of mechanically dewatered sludge, m^3; P_H – moisture content of mechanically dewatered sludge, %
40	Amount of dry matter in thermally dried sludge: $q_{avg} = \frac{q_{dry} \times (100 - P_K)}{100}$	q_{avg} – amount of dry matter in thermally dried sludge, t; q_{dry} – amount of thermally dried sludge, m^3; P_K – moisture content of thermally dried sediment, %
41	Dryer productivity by	P_{vol} – dryer capacity by moisture, t/hour;

	moisture content: $P_{vol} = \frac{W_w}{m_p}$	W_w – amount of moisture evaporated, t; m_p – number of hours of dryer operation per month
42	Volume intensity by moisture: $A_f = \frac{P_{dry}}{W_c}$; $W_c = \frac{\pi D^2}{4}$	A_f – volume intensity by moisture, kg/m³/hour; P_{dry} – dryer productivity by moisture, t/year; W_c – drum dryer volume, m³; D – diameter of the dryer drum, m; L – length of the dryer drum, m
43	Dryer productivity by dry matter: $P_{avg} = \frac{q_{avd}}{m_p}$	P_{avg} – dry matter productivity of the dryer, t/hour; q_{avg} – amount of dry matter in thermally dried sludge, t; m_p – number of hours of dryer operation per month
44	Gas consumption per 1 t of dry matter of sediment: $q_{gs} = \frac{Q_g}{q_{avd}}$	q_{gs} – gas consumption per 1 tonne of dry sediment, m³; Q_g – total gas consumption per month, m³; q_{avd} – amount of dry matter of thermally dried sludge, t
45	Gas consumption per 1 tonne of evaporated moisture: $q_{gc} = \frac{Q_g}{W_w}$	Q_{gc} – gas consumption per 1 tonne of evaporated moisture, m³; Q_g – total gas consumption per month, m³; W_w – amount of evaporated moisture, m³

Quarterly and annual reports are compiled on the basis of monthly technical reports. In the reports, quantitative indicators (number of hours of operation, repairs, amount of wastewater, sludge, slime, air, etc.) are summarised, while qualitative indicators (suspended solids, BOC, COD, etc.) are calculated as arithmetic means for 12 months. In the event of significant changes in wastewater or sludge consumption, qualitative indicators are calculated as the average proportional to wastewater consumption or sludge quantity (e.g. when calculating moisture content). The main operating parameters of individual facilities (residence time, load, etc.) are calculated using the formulas for compiling monthly reports.

Instead of monthly data (number of operating hours, amount of wastewater, sludge, etc.), quarterly or annual data is entered into the formulas.

Questions for discussion and self-assessment

1. What types of treatment facilities can be found at processing plants?
2. What is the purpose of local treatment facilities? What treatment methods are used in them?
3. What is the purpose of factory treatment facilities?
4. List the facilities for mechanical wastewater treatment.
5. What is the purpose of grates?

6. What is the purpose of sand traps?
7. What is the purpose of sedimentation tanks?
8. How are grates classified depending on the distance between the bars? Which grates are better to install in workshops, and which on the main channel?
9. List the mobile screens you know. Describe how they work.
10. How do horizontal sand traps differ from vertical ones?
11. What is the purpose of hair traps?
12. What is the essence of the process of coagulation of contaminants contained in wastewater?
13. What are the main chemicals used to treat wastewater from processing plants for the purpose of coagulating contaminants?
14. List the main mineral coagulants and describe their main characteristics.
15. What is the nature of coagulants, their classification, properties and purpose in the reagent treatment of wastewater?
16. Which microorganisms oxidise organic substances contained in wastewater?
17. Which organic substances are more easily oxidised by bacteria, and which are more difficult?
18. How does temperature affect the efficiency of biological oxidation? What causes this effect?
19. How does the pH of the environment affect the oxidising capacity of the wastewater biocenosis?
20. What is soil purification of wastewater?
21. What field irrigation systems are you familiar with? Can this method be used to treat wastewater from processing plants?
22. What is the purpose of irrigation fields?
23. What is the purpose of filtration fields?
24. What is the purpose of lagoons?
25. What are the design features of ponds with natural and artificial aeration? Name the methods of artificial aeration.
26. Provide a classification of biological wastewater treatment facilities in artificial conditions depending on the location of biomass in them.
27. Indicate the composition and properties of activated sludge. How is it used in biological wastewater treatment?
28. What is the principle of operation of biofilters?
29. How are biofilters classified by type of loading material?
30. Submerged and disc biofilters, their design features, principle of operation.
31. How are aerotanks classified?
32. What is the principle of operation of an aeration tank?
33. What is the difference between aerotanks and biotanks?

Before treated wastewater is discharged into municipal sewerage systems, water bodies or used in specific technological processes in a recirculating water supply system, it must be disinfected and rendered harmless. This is necessary because after applying most physical and chemical methods of wastewater treatment, about 90 – 95 % of bacteria are removed, and the rest may include pathogenic bacteria and viruses.

Various oxidants are used for disinfection: chlorine, ozone, technical oxygen, hydrogen peroxide, manganese oxides, permanganate and potassium dichromate.

In practice, chlorine, ozone, and sodium hypochlorite are preferred.

8.1. Chlorination

At processing plants, bleaching lime, gaseous chlorine, and sodium hypochlorite are used for chlorination of wastewater. When chlorine is introduced into water, it hydrolyses to form hypochlorous and hydrochloric acids:

$$Cl_2 + H_2O \leftrightarrow \mathbf{HOCl + HCl}$$

In a strongly acidic environment, the equilibrium of this reaction shifts to the left, and molecular chlorine is present in the water; at pH values > 4, molecular chlorine is practically absent in the water. The hypochlorous acid formed as a result of chlorine hydrolysis dissociates into hypochlorite ions OCl^- and hydrogen ions H^+.

In the presence of ammonia, ammonium salts or organic substances containing amino groups in wastewater, chlorine, hypochlorous acid and hypochlorites react with them to form mono- and dichloramines, as well as nitrogen trichloride:

$$NH_3 + \mathbf{HOCl} \rightarrow NH_2Cl + H_2O$$
$$NH_2Cl + \mathbf{HOCl} \rightarrow NHCl_2 + H_2O$$
$$NHCl_2 + \mathbf{HOCl} \rightarrow NCl_2 + H_2O$$

During wastewater disinfection, a 5% working solution of the reagent (based on active chlorine) is usually used.

If hydrogen sulphide and sulphides are present in the wastewater, the reactions proceed as follows:

- in acidic and neutral environments, sulfites may form:

$$H_2S + 3Cl_2 + 3H_2\mathbf{O} \rightarrow \mathbf{H_2}SO_3 + 6HCl$$
$$NaHS + 3Cl_2 + \mathbf{3H_2O} \rightarrow NaHSO_3 + \mathbf{6HCl}$$

- In an alkaline environment, chlorine oxidises sulphides to sulphates:

$$Na_2S + 4Cl_2 + 8NaOH \rightarrow Na_2SO_4 + 8NaCl + 4HCl$$

With an excess of chlorine, oxidation always proceeds to sulphates.

Methyl mercaptan is oxidised by chlorine slightly slower than hydrogen sulphide, but faster than sulphides and disulphides. Depending on the chlorine consumption, the oxidation of methyl mercaptan can proceed with the formation of various products:

$$2CH_3SH + Cl_2 \rightarrow CH_3SCH_3 + 2HCl$$
$$CH_3SH + 2Cl_2 + H_2O \rightarrow CH_3SOCl + 3HCl$$
$$CH_3CH + 3Cl_2 + 2H_2O \rightarrow CH_2SO_2Cl + 5HCl$$

Disinfection of wastewater from hydrogen sulphide and methyl mercaptans is quite effective when the contact time with chlorine does not exceed 5 minutes.

The essence of the disinfecting action of chlorine lies in the suppression of metabolism, as well as in the oxidation of substances that make up the protoplasm of bacterial cells, as a result of which they die.

The bactericidal effect of chlorine largely depends on the initial dose and duration of contact with water. Usually, only a small portion of the chlorine introduced into the water is used to destroy bacterial cells. Most of the chlorine reacts with various organic and mineral impurities contained in the wastewater. These reactions proceed at different rates depending on the chlorine concentration, pH and water temperature. The amount of chlorine absorbed as a result of its interaction with substances contained in water is determined as the chlorine demand of water.

The chlorine demand of wastewater is determined by the amount of chlorine in mg/dm^3 consumed during 30 minutes of contact with the test water for the oxidation and chlorination of organic substances (protein compounds, fibre) contained in it and their decomposition products (nitrites, ammonia, hydrogen sulphide, etc.).

For a comparative characterisation of the chlorine demand of different wastewater, the water chlorination index can be used, which is a conditional fraction with a numerator of 1 and a denominator of the chlorine dose that provides 0.5 mg/dm^3 of residual chlorine after 30 minutes of contact.

In practice, the required chlorine dose is determined based on the total chlorine consumption of the wastewater, which includes chlorine absorption and a certain excess of chlorine that provides a bactericidal effect for a certain period of time. The excess chlorine is necessary to prevent the possibility of secondary bacterial contamination of the water as it passes through the sewerage system, especially before discharge into a water body.

The amount of chlorine used for disinfection depends on the composition of the wastewater, the concentration and type of contaminants. According to DSanPiN 2.2.4-171-10 for preliminary calculations, the dose of active chlorine

should be 10 g/m^3 for wastewater after mechanical treatment, and 5 and 3 g/m^3 after incomplete and complete artificial biological treatment, respectively. The working dose of chlorine must be specified during the operation of treatment facilities by means of trial chlorination in laboratory conditions, on the basis of which a curve of chlorine consumption of water for 30 minutes is constructed. After 30 minutes of contact between chlorine and water, the concentration of free chlorine should be no more than 0.5 and no less than 0.3 mg/dm^3, and the total chlorine concentration should be no less than 0.8 and no more than 1.2 mg/dm^3 after one hour of contact.

As a result of chlorination, the colour and odour of wastewater are reduced, and organic substances that interfere with sedimentation and filtration are destroyed.

Water chlorination is carried out with liquid chlorine. In small water treatment complexes (up to 3000 m^3/day), the use of chlorinated lime is permitted. At above-zero temperatures and atmospheric pressure, chlorine is a greenish-yellow gas with a suffocating odour and a density 1.5–2.5 times greater than that of air, depending on the temperature. At elevated pressure, chlorine turns into a liquid state. In this form, it is stored and transported in steel cylinders weighing 25–30 and 100 kg.

The chlorine facility must ensure the reception, storage and dosing of chlorine to obtain chlorinated water. It is located in a separate building and includes a chlorine storage room, a chlorination room, a ventilation chamber, a control room and a vestibule.

Safety rules must be followed when working with chlorine. Inhaling air containing 0.10–0.15 mg/dm³ of chlorine for one hour leads to fatal poisoning.

An increase in the concentration of chlorine in the air to 2.5 mg/dm³ causes sudden death. Therefore, chlorination rooms are equipped with supply and exhaust ventilation, and the switches for turning on the fans are installed outside so that the chlorination room can be well ventilated before entering it.

The chlorination room must be heated to 22–27°^{0}C to prevent the chlorine cylinders from cooling down and to avoid a decrease in the evaporation rate of liquid chlorine.

Chlorine consumption is regulated by a valve. Chlorine is mixed with clean water in ejectors. The excess pressure of tap water before the ejector should be 0.3–0.4 MPa, with a water consumption of approximately 0.7 m³ per 1 kg of active chlorine. Chlorine is mixed with water in a special glass cylinder.

Chlorous acid salts – chlorinated lime and sodium hypochlorite – are also used to disinfect wastewater.

Chlorinated lime – $Ca(OCl)_2 \cdot CaCl_2 \cdot H_2O$ – is a double salt obtained by cold chlorination of lime slurry – a mixture of $Ca(OH)_2 \cdot CaCO_3 \cdot H_2O$.

It is a white powder with a characteristic chlorine odour. Water in chlorinated lime is present not as a medium, but as a component of reacting substances. Under the influence of carbon dioxide, moisture and light, chlorinated lime decomposes with the release of Cl_2, HOCl, ClO^- into the solution or the environment.

The quality of the reagent used for water disinfection is determined by the

active chlorine content. Technical chlorinated lime must contain at least 32–35% active chlorine. To avoid loss of activity due to the interaction of chlorinated lime with water and carbon dioxide in the atmosphere, it is transported and stored in closed containers. A chlorination plant operating on chlorinated lime consists of: a unit for preparing and dosing the solution, a storage area for lime barrels and a vestibule.

The chlorinated lime solution is prepared in a tank made of wood, metal or plastic and equipped with a mixer. The solution is dosed using a float valve, which maintains a constant level in the dosing tank, or dosing pumps.

The use of chlorinated lime for wastewater disinfection requires special permission due to the shortage of the reagent. Therefore, the use of this disinfection method is problematic.

Sodium hypochlorite is obtained by the reaction of chlorine with a cold alkali solution:

$$Cl_2 + \mathbf{2NaCl} \leftrightarrow \mathbf{NaClO} + MaCl + H_2O$$

This reaction occurs when gaseous chlorine is passed through an alkali solution. Solutions of chlorous acid salts contain 15–16% active chlorine and are always hydrolysed.

In addition, sodium hypochlorite is obtained by electrolysis of a sodium chloride solution. The method is based on obtaining chlorine and its interaction with alkalis in the same apparatus – an electrolyser. During the electrolysis of NaCl in a bath without a diaphragm, chlorine ions decompose at the anode:

$$2Cl^- \rightarrow \mathbf{Cl_2} + 2e$$

The chlorine released dissolves in the electrolyte to form hypochlorous acid and hydrochloric acid:

$$Cl_2 + H_2O \leftrightarrow HClO + HCl \quad \text{or} \quad Cl_2 + OH^- \leftrightarrow \mathbf{HClO} + Cl^-$$

At the cathode, water molecules are split:

$$H_2O + e \leftrightarrow OH^- + H^+$$

Hydrogen atoms are released from the solution in the form of gas, while OH^- ions remaining in the solution form alkali near the cathode with Na^+ ions. When hypochlorous acid reacts with alkali, sodium hypochlorite is formed:

$$HClO + NaOH = NaClO + H_2O$$

Sodium hypochlorite is equivalent to liquid chlorine in terms of its bactericidal action.

The industry produces EN non-flow-through electrolysers with a capacity of 1 to 100 kg of active chlorine per day and EOV flow-through electrolysers with a capacity of 25 kg of active chlorine per day.

A non-flow-through electrolyser (Fig. 8.1) is a tank made of corrosion-resistant material containing a block of graphite electrodes 6. The electrolysis plant comprises a solution tank 1, a tank 2 with a pump 5 for preparing the salt solution, a sodium hypochlorite storage tank 8, rectifiers, and an exhaust ventilation system 7.

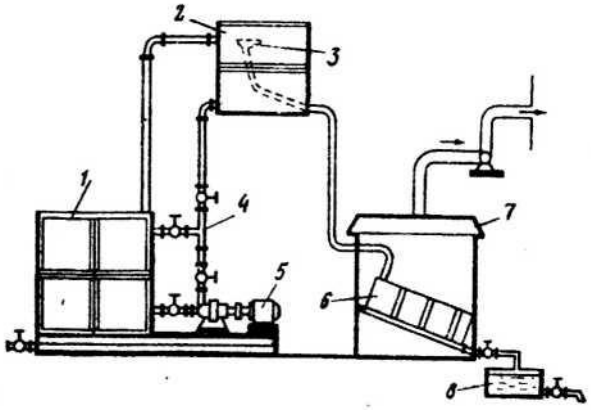


Fig. 8.1. Diagram of a non-flow-through electrolysis system
1, 2 – solution and working tanks; 3 – float dispenser; 4 – distribution tee;
5 – pump; 6 – electrolyser; 7 – exhaust ventilation hood;
8 – sodium hypochlorite filling tank

A non-flow-through electrolysis unit operates as follows. Table salt is added to the solution tank, water is poured in, and the mixture is stirred until a saturated solution of table salt is obtained (280–300 g/dm³). The solution is then pumped into the working tank, where it is diluted with tap water to a low concentration (100 – 120 g/dm³). From this tank, the electrolyte is fed via a dosing unit into the electrolyser. The finished product is drained into a storage tank, from where it is dosed into the water being treated. The solution must remain in contact with the wastewater for at least 30 minutes. For every 1 kg of active chlorine, 8–15 kg of salt and 7–12 kWh of electricity are consumed, depending on the electrolyser's capacity. Salt is loaded into the tank once every 15–50 days, depending on chlorine consumption. It is recommended that electrolysers be installed in a separate room.

Treating wastewater with sodium hypochlorite is virtually equivalent in cost to treatment with chlorine and is 1.5–2 times cheaper than disinfection with chlorinated lime.

Various types of mixers installed in the sewage channel are used to mix sewage with chlorinated water.

The two-section contact tank has a section width of 6 m, a total length of 9 m and a working depth of 3.1 m. Wastewater is agitated by compressed air at a rate of 0.5 m³/(m²·h). Contact tanks act as settling tanks, as the coagulating action of chlorine causes sediment to precipitate from the wastewater. Sediment removal is carried out periodically after the settled water has been drained. Contact tanks may not be required if the residence time of the wastewater from the chlorine injection points to the outlet exceeds 30 minutes.

8.2. Ozonation

A promising method of water disinfection is treatment with ozone. Ozone (O_3) is a blue gas with a characteristic odour that can be detected when diluted with air in a ratio of 1:500,000. Ozone is one of the strongest oxidants. It dissociates in air and in aqueous solutions, breaking down into a molecule and an oxygen atom. Ozone acts as a disinfectant 15–20 times faster than chlorine. Simultaneously with disinfection, ozone causes water discolouration and deodorisation. When ozone is introduced into water, it oxidises the enzymes of bacterial cells and even most organic substances.

Ozone is capable of breaking down phenols contained in wastewater from smoking production, forming aldehydes, glyoxal, oxalic and dicarboxylic acids, hydroperoxide, and carbon dioxide. At relatively high concentrations of phenol in water (over 50–200 mg/dm^3), the oxidation process proceeds at the same rate regardless of the pH of the solution. The ozone consumption for the oxidation of 1 g of phenol can reach 5–10 g.

Ozonation is an effective method for purifying wastewater from anionic and non-ionic surfactants used in the sanitary treatment of technological equipment and product processing technology. This method can be used for additional purification of biochemically treated wastewater from biologically heavy substances.

Ozone does not alter the natural properties of water, as its excess (unreacted ozone) is converted into oxygen within a few minutes. Thus, an ozone concentration of 2.5 mg/dm^3 decreases to 1.5 mg/dm^3 after 20 minutes and to 1 mg/dm^3 after 45 minutes. At a pressure of 0.5 MPa and a temperature of 0°^{0}C, the solubility of ozone is 1.42 mg/dm^3.

In the presence of acids and salts, the solubility of ozone in water increases, and in the presence of alkalis, it decreases. The oxidation potential of ozone in an acidic environment is 2.07 V, and in an alkaline environment, it is 1.24 V. Its MPC in air is 10^{-5}mg/dm^3.

The dose of ozone required for water disinfection is usually between 0.5 and 5 mg/dm^3 depending on the content of oxidisable substances in the water. Water temperature, pH, turbidity and other properties of water have a much smaller effect on the effect of ozonation than on chlorination, which facilitates reagent dosing and control of the effectiveness of water ozonation.

The ozone used for ozonation is obtained from atmospheric air in ozonators as a result of the effect of a «silent» electric discharge, accompanied by the release of ozone. Such a discharge is formed in a narrow gas space between two electrodes, to which a current with a voltage of 5–25 kV is applied. Ozonators use glass electrodes, the inner surface of which is coated with a metal amalgam (copper-graphite conductive coating). Its layer is a high-voltage electrode.

Industrial ozone generators use tubular or plate elements. Ozone generators are usually made in the form of cylindrical containers, in which several dozen parallel tubular ozonising elements are located, consisting of two concentrically arranged glass tubular electrodes. The body of the device is grounded. Air moves along the axis of the ozonising elements in the annular space between the

concentrically arranged electrodes.

Oxygen molecules are broken down by electrical discharges, and the resulting atoms easily attach to whole molecules, forming an ozone molecule:

$$O + O_2 \leftrightarrow O_3$$

The oxygen atom released in this reaction can interact with the ozone molecule with the release of heat:

$$O + O_3 \leftrightarrow 2O_2 + 400\ kJ$$

The air used in the devices must first be freed from moisture and dust. Even traces of moisture entering the discharge space of the device cause a spark discharge, which reduces the performance of the ozonator – ozone output decreases and electricity consumption increases approximately 4 times.

The technological scheme of wastewater ozonation (Fig. 8.2) consists of two main units: ozone generation and wastewater treatment.

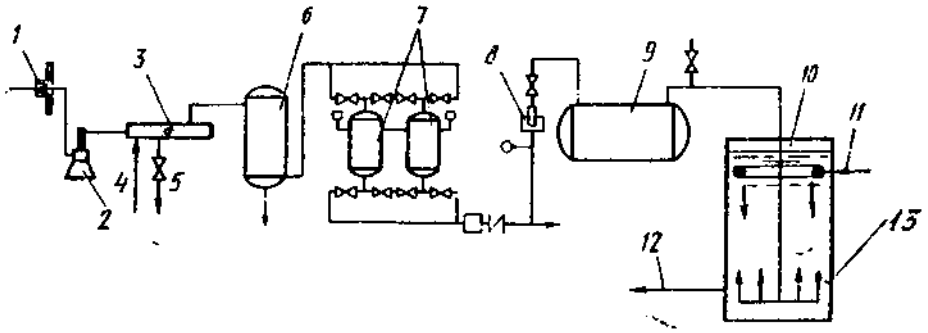


Fig. 8.2. Diagram of an ozonation unit

1 – air filter; 2 – air blower; 3 – water heat exchanger; 4,5 – cooling water supply and discharge; 6 – adsorber; 7 – moisture absorption filters; 8 – flow meter; 9 – ozonator; 10 – contact tank; 11,12 – supply and discharge of ozonated water; 13 – ozone-air mixture sprayer

The ozone generation unit consists of four main blocks: air intake and cooling, drying, air filtration, and ozone generation. Atmospheric air is fed through the air intake shaft to filter 1, where it is cleaned of dust and fed by air blowers 2 to the droplet separator 3, and then to automatic air drying units loaded with active alumina 6.

Dehumidified air enters automatic filter units, where it undergoes fine dust removal. The dried and purified air is fed into ozonator units 9, where ozone is generated by an electric discharge. Together with the air, the ozone-air mixture is directed into the contact chamber 10 and mixed with the treated wastewater. The ozone-air mixture is sprayed through porous ceramic tubes 13. The treated wastewater or ozone-air mixture moves in opposite directions in the contact chamber, which ensures greater ozonation efficiency.

Interaction chambers can be single-stage or two-stage. The ozone-air mixture is also mixed with wastewater in absorbers with various nozzles (Ratita rings, chord nozzles, etc.), in ejectors and by other means.

When calculating contact reaction chambers, first of all, the area of the spray

elements is determined, which are placed near the bottom of the chamber for uniform distribution of the ozone-air mixture in the water. When using metal-ceramic or ceramic pipes with pores measuring 40–100 or 60–100 micrometres as distribution devices, the optimal dispersion mode is achieved at a spray intensity of 76–91 and 20–26 $m^3/(m^2 \cdot h)$.

The total area of all spraying elements of a bubbling-type contact chamber can be determined by the formula:

$$f_{TOTAL} = Q \cdot d_{oz}/(C \cdot \omega),$$

where f_{TOTAL} – total area, m^2 ;
Q – wastewater flow rate, m^3/hour;
d_{oz} – required ozone dose, g/m^3 ;
C – ozone concentration in the mixture, g/m^3;
ω – spray intensity per unit of time, $m^3/(m^2 \cdot hour)$.

Number of spraying elements:

$$N = f_{TOTAL}/f_E,$$

where f_E – area of one spraying element.

Metal-ceramic spraying pipes should be located at the bottom of the contact chambers at a distance of 0.4 m, and ceramic pipes – at a distance of 0.5 m between the axes. With this pipe arrangement, the bubbling torches are combined at a height of 2 m.

The total volume of the chamber is calculated using the following formula:

$$W = K_{pr} \cdot Q \cdot t,$$

where W is the total volume of the chamber, m^3;
K_{pr} – coefficient of water volume increase due to its blowing with an ozone-air mixture, usually 1.1;
t – duration of wastewater stay in the reaction chamber, hours.

The values of d_{oz} and t are determined experimentally for each type of industrial wastewater. The height of the water layer above the sprayer H= 4.5–5 m.

In two-stage reaction chambers, the height of the water layer in each stage is 2.5–2.8 m. Contact chambers can be rectangular or circular in plan, and there must be at least two of them.

The required amount of ozone (D_{oz}, g/hour) is determined based on the expression:

$$D_{oz} = d_{oz} \cdot Q/1000$$

The number of ozonisers is determined based on their productivity:

$$m = K \cdot D_{oz}/ d_{oz},$$

where K is the reserve coefficient, which is taken to be equal to 1.05 – 1.10;
d_{oz} is the productivity of one ozonator.

It has been established that ozone effectively oxidises aqueous solutions containing phenols, non-ionic and anionic surfactants, oil and other organic substances. Thus, the oxidation of hydrogen sulphide occurs in two stages. In the first stage, sulphur is released, and in the second stage, oxidation occurs directly to H_2SO_4:

$$H_2S + O_3 \rightarrow \mathbf{S} + O_3 + H_2O$$
$$2H_2S + 4O_3 \rightarrow 2H_2SO_4 + 2O_2$$

The reactions occur simultaneously, but when there is an excess of ozone, the second reaction prevails.

The consumption of ozone for the destruction of pollutants in wastewater depends on many factors: pH, concentration of pollutants and ozone, mixing methods and duration of contact of the ozone-air mixture with the treated wastewater, etc.

The electricity consumption for producing 1 kg of ozone from well-dried air for different types of ozonisers is 13–29 kWh, and from undried air – 43–57 kWh.

The power consumption for drying and compressing air to obtain 1 kg of ozone is 6–10 kW.

The ozonation process can be intensified by combining it with ultrasound or ultraviolet radiation.

8.3 Disinfection with ultraviolet rays

The entire ultraviolet (UV) spectrum of sunlight is divided into the normal spectrum and the vacuum spectrum.

The normal UV spectrum is in turn divided into the near (400–300 nm) and far (300–185 nm) regions. The short-wave part of the UV spectrum with a wavelength of 200–295 nm has the greatest bactericidal effect, with rays with a wavelength of 260 nm being the most effective.

The bactericidal properties of UV rays are associated with their effect on protein molecules and enzymes in the cytoplasm of cells, causing their death.

The UV disinfection process is influenced by a number of different factors, including the irradiation dose, water quality, flow rate, type of microorganisms, design of the equipment, etc.

Disinfection of water with UV rays has a number of advantages over chlorination. These rays do not affect its natural organoleptic properties. The bactericidal action of UV rays is much faster than that of chlorine, affecting microorganisms almost instantly. The advantage is that not only vegetative forms of bacteria are destroyed, as in chlorination, but also their spores. In addition, UV water treatment requires simple equipment, which is much easier to operate than complex equipment for chlorination and ozonation.

Purified, transparent water with a colour index of no more than 20 ^{0}is best

suited for UV disinfection, as suspended and colloidal substances scatter light and prevent the penetration of UV rays. The sources of UV rays are mercury lamps made of quartz or ultraviolet glass (ordinary glass does not transmit UV rays). The lamps are shaped like tubes with a diameter of 15–20 mm with oxide electrodes at the ends. Under the action of electric current, mercury vapours produce a bright greenish-white colour rich in UV rays.

There are two main types of irradiation devices: devices with immersed and non-immersed UV sources.

Devices with immersed sources are characterised by a high radiation power utilisation coefficient, but they are structurally complex, especially at high productivity.

Devices with non-immersed sources are very simple in design, but they inefficiently lose part of their bactericidal power due to the scattering of rays, their absorption by reflective surfaces, etc. Therefore, in practice, devices of the first type are used.

Microorganisms in water have varying degrees of resistance to bactericidal rays, and the value of the K coefficient depends on the type of bacteria.

The resistance coefficient of various types of vegetative pathogenic bacteria practically does not exceed the resistance coefficient of coliform bacteria, which is approximately 2500, which is taken into account when calculating the required amount of bactericidal energy for disinfection.

When determining bactericidal energy, its absorption when the beam passes through a layer of water should be taken into account.

For water from surface water sources that has not been treated at treatment facilities, the absorption of bactericidal energy is 0.2 – 0.3 cm^{-1}. These values are accepted with a margin, taking into account possible deviations in water quality indicators for turbidity and colour from the requirements.

The electricity consumption (S, W • h/m^3) for water disinfection is calculated using the formula:

$$S = \mathbf{N \bullet n/q},$$

where N is the power consumption, W (Table 8.1).

Table 8.1. Main design parameters of bactericidal lamps

Lamp type	Bactericidal energy flow, W	Power, W
UV-30	2	30
BUV-60P	6.5	60
PRK-7	35	1000
RKS-2.5	–	6000

The most common sources of bactericidal radiation are high-pressure mercury-quartz lamps PRK and low-pressure lamps RKS-2.5. High-pressure mercury-quartz lamps (0.05–0.1 MPa) with a shell temperature of 250–300 ^{0} C, are powerful sources of visible light and UV rays with maximum radiation in the wavelength range of 365–366.3 nm. The percentage of bactericidal energy

emitted by these lamps is small, but due to their significant electrical power (up to 2.5 kW), a significant bactericidal effect is achieved.

The most economical are special low-pressure argon-mercury lamps of the BUV type, which are called bactericidal lamps. The lamp tube made of ultraviolet glass contains a mixture of mercury vapour and argon under a pressure of 399 – 532 Pa. The temperature of the bulb during lamp operation is $40^{\circ 0}$C.

About 70% of the total radiated power of these lamps is in the invisible UV range with a wavelength of 253.7–306.6 nm, and about 60% is in the wavelength range of 253.7 nm. Due to the high bactericidal flux, the efficiency of BUV lamps is several times higher than that of high-pressure mercury-quartz lamps.

The relatively low power of industrially manufactured argon-mercury lamps allows them to be used in low-capacity installations in recirculating water consumption systems in certain technological processes, for example, when cooling canned food directly in an autoclave.

High-pressure mercury-quartz lamps, although less economical than argon-mercury lamps, can be used to disinfect large quantities of water with low bacterial contamination. Their use is more economical than disinfection by chlorination.

Most modern installations are equipped with means of automatic control of the intensity of UV radiation or the duration of lamp burning. Bactericidal installations are equipped with various devices for cleaning the quartz cover from suspended solids: scrapers, brushes, etc., as well as devices that operate automatically from water pressure or a special drive.

Table 8.2 shows the main types of installations used for water disinfection with bactericidal UV rays.

Table 8.2. Types of bactericidal installations and their characteristics

Type of installation	Water capacity, m^3 /hour	Maximum water pressure, MPa	Lamp type	Number of lamps	Installation power consumption, W
OV	3	0.5	BUV-60P	1	0.06
OV-AKH-1 double chamber	60	0.5	PRK-7M	2	2
OV-AKH three-chamber	90	0.5	PRK-7M	3	3
OV-Sh-RKS	50 – 70	1	RKS-2.5	1	6
OV-ZP-RKS	150 – 200	1	RKS-2.5	3	18

The OV-1P bactericidal unit is designed for low water flow rates (up to 2–3 m^3/h). When treating large volumes of water, several units are operated in parallel. Figure 8.3 shows such a unit. It consists of a housing *1* with a single

BUW-60P *6* bactericidal lamp, which is housed in a cylindrical quartz sleeve 5, situated on the axis of the chamber housing *1*.

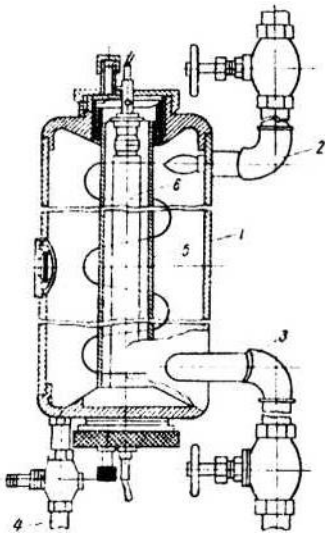


Fig. 8.3. Design of a unit with a single submerged OV-1P germicidal lamp:
1 – unit housing; 2 – outlet pipe; 3 – inlet pipe;
4 – drain valve; 5 – quartz sleeve; 6 – germicidal lamp

The power button and the control unit for the germicidal lamp are mounted directly onto the unit's housing. Water enters the unit through the lower inlet pipe *3* and is discharged through pipe *2*. Inside the unit there is a coil which imparts a rotational movement to the water, promoting good mixing of the flow. As it flows over the quartz sleeve, the water is evenly irradiated and disinfected.
The unit is installed indoors at a temperature not lower than $+5^{\circ 0}$C vertically on the pipeline after the pump or directly at the water consumer. It requires a 220 V alternating current to operate. It is necessary to periodically (1-2 times a month) clean the quartz cover from the sediment that accumulates on it. Cleaning is carried out without turning off the unit by making several reciprocating movements of the spiral, which is moved using a handle.

To intensify the water disinfection process, the inner surface of the housing, which reflects UV rays, is sometimes polished, as an unpolished inner surface absorbs approximately 40% more radiation than a polished one.

The water treatment scheme using a UV unit sometimes includes an ejector, which allows the ozone formed in the internal space of the quartz housing to be utilised.

A flow diagram of the system with an ejector is shown in Figure 8.4. It works as follows. Ozone, which is generated in the air space within the quartz sleeve, is drawn into the water supplied by pump *2* via ejector 6, which is connected in series. For this purpose, the upper end of the quartz tube is fitted with a cap featuring a connector *8*, through which the UV unit is connected to the ejector. The water, mixed with ozone, enters the working zone via the inlet pipe *9*, is disinfected by the action of UV rays and ozone, and exits via the outlet pipe *10*.

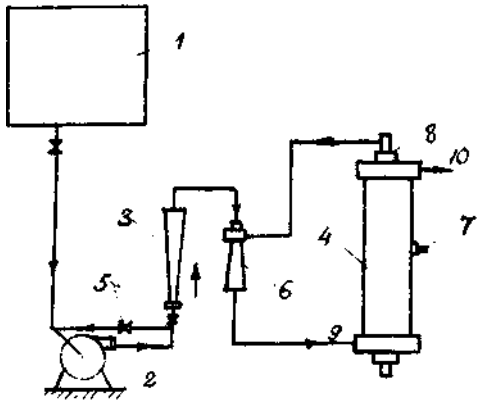


Fig. 8.4. Process flow diagram for water treatment in a UV system
1 – raw water tank; 2 – centrifugal pump; 3 – rotameter; 4 – UV system;
5 – flow control valves; 6 – ejector; 7 – UV radiation intensity sensor; 8 – cap with connector;
9 – water inlet; 10 – water outlet after disinfection

It has been established that the introduction of the ozone produced into the water enhances the bactericidal effect only in relation to the most sensitive microorganisms – ***Escherichia coli*** and ***Proteus vulgaris.***

The OV-3P-RKS-type bactericidal unit is designed for a flow rate of 3,000 m³/h and above (Fig. 8.5). It is installed in channel 6 in the form of a frame cassette 1, on which blocks containing RKS-2.5 lamps 2 are mounted. Several lamps, protected by quartz cylindrical sleeves, are mounted in the cassette.

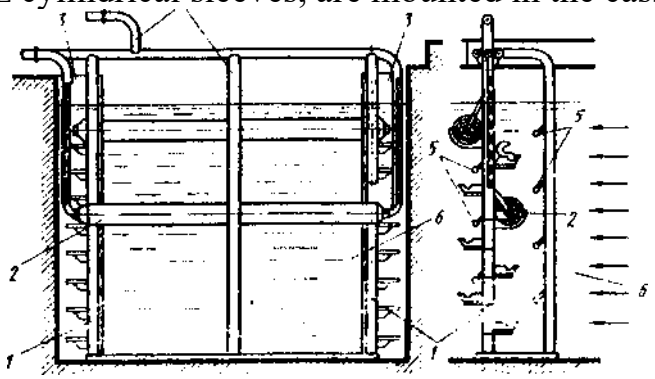


Fig. 8.5. OV-ZP-RKS-type bactericidal unit
1 – metal frame with brackets; 2 – units with RKS-2.5 bactericidal lamps;
3 – metal plates; 4 – pressurised water pipeline for washing the covers; 5 – wash nozzles;
6 – channel for the water to be treated

To ensure a turbulent water flow and good mixing in the channel during irradiation, the lamps are arranged in a staggered pattern.

The channel, fitted with cassettes, is covered at the top by removable lids. A control panel with the lamp starting equipment is located next to the channel. The power consumption for irradiating water from open water sources that has been treated at water treatment plants is up to 30 W·h/m³.

A disadvantage of this disinfection method is the lack of real-time monitoring of the disinfection effect (unlike chlorination, which monitors residual

chlorine). Furthermore, the irradiation method is unsuitable for disinfecting turbid water.

Questions for discussion and self-assessment

1. What oxidants are used for wastewater disinfection?
2. What preparations are used for chlorination of wastewater?
3. What concentration of active chlorine is used for wastewater disinfection?
4. What does active chlorine consume more of when chlorinating wastewater: disinfection from bacteria or oxidation of organic substances in water?
5. Define the concept of chlorine demand in wastewater.
6. In what form is pure chlorine supplied for water chlorination, how is it stored and dosed into wastewater?
7. What is the active chlorine content in chlorinated lime?
8. Describe the method of preparation and dosing of the chlorinated lime solution used for wastewater disinfection.
9. Describe the process of obtaining sodium hypochlorite in a non-flow-through electrolyser.
10. List the main properties of ozone as an oxidising agent.
11. What are the advantages of using ozone for wastewater disinfection?
12. How does the pH of the aqueous medium affect the solubility of ozone?
13. What are the ozone doses for wastewater disinfection?
14. Why is the air used in ozone generation devices pre-cleaned of dust and moisture?
15. Describe the technological scheme of wastewater ozonation.
16. What factors determine the ozone consumption for wastewater disinfection?
26. What is the maximum permissible concentration of ozone in the air?
27. How do UV rays exhibit their bactericidal properties?
28. What factors influence the process of wastewater disinfection by UV irradiation?
29. List the advantages and disadvantages of wastewater disinfection by UV irradiation compared to chlorination.
30. Is it possible to disinfect turbid wastewater with UV rays?
31. Why can't ordinary glass be used to make UV lamps? What kind of glass is used?
32. What devices are most often used for disinfecting wastewater with submersible or non-submersible UV light sources, and why?
33. Describe the characteristics of BUV-type UV lamps.
34. What devices do you know of for cleaning quartz glass in bactericidal lamps from suspended solids?

CHAPTER 9. RECLAIMED WATER SUPPLY AND WASTEWATER WASTE DISPOSAL

9.1. Wastewater recycling

In order to make more rational use of drinking-quality water and to reduce the load on factory treatment facilities, it is recommended to organise recycled water consumption in production processes, including the purification, cooling and disinfection of waste water. Various methods are commonly used to treat and disinfect wastewater, but additional treatment is required to achieve the required quality of recycled water. For example, in the practice of creating a recycled water consumption system at fish processing enterprises in the Azov-Black Sea basin, two main methods are used for additional treatment: filtration through activated carbon (sorption method) and through porous membrane filters (ultrafiltration method).

9.1.1. Methods of wastewater post-treatment

As a result of deep treatment (additional treatment), it becomes possible to reuse treated wastewater in technological processes, which saves a significant amount of fresh drinking water. Methods that do not require large production areas, complex equipment and cumbersome reagent management are particularly interesting. Such methods include ultrafiltration and sorption.

Ultrafiltration

Ultrafiltration is a membrane method for separating wastewater containing finely dispersed substances, colloidal and high-molecular soluble substances. This method allows not only for the additional purification of wastewater to meet the standards for water used in circulation, but also for the concentration of valuable substances contained in the water.

In the food industry, membrane separation methods are used to obtain high-quality sugar, pasteurise beer, stabilise wine, concentrate whey proteins, fruit and vegetable juices, and extract valuable components from wastewater. In the fishing industry, membrane methods are used to concentrate press broth in the production of fish meal, to further purify brine during its repeated use, and to treat wastewater from the cooling of canned fish directly in autoclaves.

Ultrafiltration is carried out through porous membranes, whereby low-molecular substances, such as water and table salt, freely pass through the membrane, while high-molecular and suspended substances are retained. The main working element of ultrafiltration equipment, which determines both the design of the apparatus and the process of liquid separation, is a semi-permeable membrane.

The essence of the ultrafiltration process is that the treated liquid is pumped under pressure over the membrane. In this case, low-molecular fractions pass through the membrane, while high-molecular fractions remain in the liquid flow above the membrane. In this way, the liquid being treated is separated.

As the viscosity and osmotic pressure of the solution increase, the performance of the internal membrane may decrease to such an extent that its use becomes impractical. A gel-like layer forms on the membranes, disrupting the filtration process, so the membranes must be periodically flushed to restore permeability.

The decrease in filtration rate is associated with an increase in the concentration of contaminants on the membrane surface. This phenomenon is called *concentration polarisation*.

To reduce the effect of concentration polarisation, turbulent flow conditions are created using mechanical devices, as well as periodic flushing of ultrafiltration membranes with warm water or various cleaning solutions (nitric acid, caustic soda, syntanol, DS-10, etc.) depending on the composition of the contamination and the membrane material.

The efficiency of membrane processes largely depends on the properties of the membranes used. High permeability, high selectivity, high physical and chemical stability over a significant period of time are the main requirements for membranes from an economic point of view.

Membranes used in industry are divided into inorganic (metal, ceramic, glass) and organic or polymer films, tubes, and polyfibres. The structure of these membranes can be elastic, rigid or combined. Elastic semi-permeable membranes are made from polyamides, polyurethanes, polyvinyl, cellulose, polyacrylonitrile, etc. Rigid membranes are, for example, glass capillaries with a diameter of 0.5 – 1.5 mm and a wall thickness of 0.1 – 0.3 mm. These membranes are thermally and chemically stable but have low selectivity.

Ultrafiltration units are assembled from modules, the number of which depends on the wastewater flow rate. A single membrane module consists of one or more elements containing a semipermeable membrane and a drainage system, as well as housing parts with inlet and outlet pipes.

Depending on the type of membranes and the method of their installation, the devices are divided into four types: devices with plate membrane elements, with tubular elements, in the form of polyfibre and roll types. Depending on the location of the membrane elements, the devices are divided into horizontal and vertical types.

The membrane is installed in frames cut between the membranes of the chamber through which the wastewater flows. The shape of the elements affects the flow organisation and the characteristics of the distribution process. The distance between adjacent membrane elements is 0.5 – 5 mm. The separated solution passes sequentially between all membrane elements, is concentrated and removed from the apparatus. The second part of this solution, passing through the membrane in the drain, forms the filtrate. These modules are more often used to concentrate valuable substances contained in water. Sometimes, turbulators in the form of corrugated film made of a special woven mesh are used to turbulise the flow. This design solution ensures easy installation and removal of individual membrane modules. These devices have a total membrane surface area of 100 – 200 m^2/m^3.

Tubular membrane modules with a total membrane surface area of 100 – 1200 m^2/m^3 are widely used. They are easy to maintain. They are constructed in the form of a multilayer pipe. The tubular membrane element consists of a membrane and a drainage frame. The drainage frame is made of fibreglass or carbon fibre tubing and a microporous substrate. The tube supports the membrane element and provides drainage for the filter. The substrate prevents the tube from being pressed into the drainage channel under the influence of the working pressure of the separation mixture. Tangential filtration mode is used here. Such modules are mainly used for wastewater with heavy contamination with suspended particles. Tubular modules are easy to clean with chemical reagents. They are more often used for wastewater treatment in recirculating water consumption systems.

Roll modules with an internal surface area of 300 – 800 m^2/m^3. Rolled elements are formed from several packages, each of which consists of two flat rectangular membranes in the form of a sandwich surface with a working surface facing outwards and glued on three sides of the rectangle.

Inside such a double-membrane package, there is a material with channels for filter drainage. The open edge of the package is adjacent to the drainage filter tube, in which holes have been pre-made. A plastic mesh acts as a partition, separating one bag from another, and provides the necessary turbulence of the filter flow. The membrane bags, together with the plastic mesh, are wound onto a tube that serves to drain the filter, resulting in a cylindrical package that is secured with adhesive tape. The separated solution is introduced into the open end of the element (at the end). Then the solution, flowing around the wall, passes parallel to the tube and reaches the second open end. At the same time, the filtrate penetrates through the membrane, flows down the drainage material and is discharged through the central tube. The packing density in such a module is higher than in a flat-parallel one. Usually, several roll modules are assembled in a single high-pressure vessel, where they are connected in series by a central filter manifold.

Devices with small diameter (45 μm) polyfibre membranes have a total surface area of up to 20,00 m^2/m^3. Acetylcellulose or nylon fibres are assembled into bundles 2 – 3 m long and placed linearly in the device. Polyfibre membrane modules can consist of hundreds or thousands of polyfibres.

Inside the apparatus housing, which has fittings for supplying the feed solution, filter (permeate) and concentrate outlets, a bundle of multifibres is installed, which is assembled using a spiral thread, ensuring a small gap between the individual fibres. This improves the distribution of the separated solution in the bundle. The separated liquid can be pumped both along the outer surface of the multifibres and through capillary channels. Due to its design features, this device cannot be used to treat solutions containing fresh particles.

In the fishing industry, porous membranes made of lavsan, cellophane, various cellulose esters, nylon, other polymers, as well as porous glass and metal ceramics are used to treat wastewater. Wastewater treatment is more often carried out in tubular ultrafilters, which can be installed in the flow.

Wastewater is fed by a pump to the suction side of the circulation pump, which increases the flow rate of the liquid, thereby increasing the efficiency of filtration. The circulation pump feeds the wastewater through the filter to the elements of the ultrafiltration module, where low-molecular substances (filtrates) pass through the pores of the membrane and are removed from the unit. High-molecular compounds remaining in the module are mixed with a new flow of liquid entering the module and are then fed either to the circulation tank, the feed tank, or to the circulation pump for re-feeding into the ultrafiltration module. The process continues until the treated liquid reaches the specified concentration. The flow of liquid into the module is regulated by a control valve. The installation may include several modules, which are connected either in parallel (to increase the productivity of the entire ultrafiltration installation) or in series (to increase the cleaning effect of the treated liquid). When connected, the wastewater after leaving the cartridge of the first module is directed to the second, and so on.

Additional treatment of wastewater by other ultrafiltration methods or the extraction of valuable components from it in concentrated form has a number of advantages over other methods: simplicity and compactness of the units, high distribution efficiency, and the possibility of process automation.

Sorption

Sorption is the process of absorbing a substance from a solid or liquid medium. The absorbing body is called a sorbent, and the absorbed substance is called a sorbate. A distinction is made between the absorption of a substance by the entire mass of the liquid sorbent (absorption) and by the surface layer of the solid sorbent (adsorption). Sorption accompanied by a chemical interaction between the sorbent and the absorbed substance is called chemisorption.

Sorption is one of the most effective methods for deep purification of wastewater from dissolved organic substances, especially weakly concentrated water in a recirculating water consumption system. Under the action of the force field of the adsorbent, the molecules of the dissolved substance move from the solution to the surface of the adsorbent. In this case, two types of intermolecular interaction are observed: the molecule of the dissolved substance with the molecules (or atoms) of the sorbent surface and the molecularly dissolved substance with the water molecules in the solution (hydration). The diversity of these two forces of intermolecular interaction is the force with which the extracted substance is retained on the surface of the sorbent. The greater the hydration energy of the dissolved substances, the greater the resistance these molecules experience when moving to the surface of the sorbent and the weaker the substances are sorbed from the solution.

Various artificial and natural porous materials, ash, coke blister, peat, silica gel, active clays, etc. are used as sorbents. Activated carbon of various grades is an effective sorbent. The porosity of these carbohydrates is 60–70%, and the total surface area is 400–900 m^2/g.

The adsorption properties of activated carbon depend on the structure of the pores, their size, and size distribution. Depending on the predominant pore size,

activated carbon is divided into coarse- and fine-pored, as well as mixed types. Pores are divided into three types according to their size: macropores with a size of 0.1–2.0 micrometres, transitional pores with a size of 0.004–0.1 micrometres, and micropores with a size of less than 0.004 micrometres.

Macropores and transitional pores play a predominant role as transport channels, while the sorption capacity of carbon is mainly determined by its microporous structure. Dissolved organic substances with particle sizes less than 0.001 micrometres fill the volume of the sorbent's micropores, the total capacity of which corresponds to its absorption capacity.

Sorption activity is characterised by the amount of absorbed substance per unit volume or mass of sorbent (kg/m^3, kg/kg).

The sorption process can take place under static conditions, in which the liquid particle does not move relative to the sorbent particle, i.e. it moves together with the latter (devices with mixing devices), as well as under dynamic conditions, in which the liquid particle moves relative to the sorbent (filters, devices with a fluidised bed).

The static activity of the sorbent is characterised by the maximum amount of substance absorbed per unit volume or mass of the sorbent until equilibrium is reached at a constant liquid temperature and initial concentration of the substance. The dynamic activity of the sorbent is characterised by the amount of substances absorbed per unit of volume or mass of the sorbent until the sorbed substance appears in the filtrate when wastewater is passed through the sorbent layer. The dynamic activity in industrial sorbers is 45–90% of the static activity. An equilibrium is established between the amount of substances adsorbed by the sorbent and those remaining in the solution in diluted solutions, which is maintained by the law of distribution.

Sorption is a reversible process, i.e. the adsorbed substance (sorbat) can pass from the sorbent back into the solution. Under other equal conditions, the rate of direct (sorption) and reverse (desorption) processes is proportional to the concentration of the substance in the solution and on the surface of the sorbent. Therefore, in the first moments of sorption, i.e. at the maximum concentration of the substance in the solution, the sorption rate is also maximum. As the concentration of the dissolved substance on the sorbent surface increases, the number of sorbed molecules returning to the solution increases. From the moment when the number of molecules sorbed from the solution (per unit of time) equals the number of molecules passing from the sorbent surface into the solution, the concentration of the solution becomes constant; this concentration is called equilibrium. If, after reaching adsorption equilibrium, the concentration of the treated solution is slightly increased, the sorbent will be able to extract some more dissolved substance from it. However, the equilibrium disturbed in this way will be restored only until the sorption capacity (ability) of this sorbent is fully utilised, after which an increase in the concentration of the substance in the solution does not change the adsorption value.

Depending on the diameter of the column, the conical bottom has a central angle of 30–60 ^{0}. Directly under the conical bottom, a distribution grid 9 with a

hole size of 5–10 mm and a hole pitch of about 10 mm is installed, onto which activated carbon with a particle size of 0.25–1 mm and a predominant fraction content of 0.5–0.75 mm is loaded. The height of the stationary coal layer is 2.5–2.7 m.

Wastewater enters the lower part of the apparatus through a central pipe ending in a diffuser under the grid, or through a side pipe of a tee connected to the conical bottom, at a rate that ensures a layer expansion of 1.5–1.6.

Coal is fed evenly into the apparatus from a hopper with an automatic dispenser. The sorbent in the form of a 5–20% suspension enters the upper expanded part of the same central pipe through which wastewater is fed into the adsorber column. In the pipe, this water mixes with the coal. The resulting suspension enters through the diffuser under the grate, is pressed through its holes and is retained in the lower part of the fluidised coal layer in the column. The spent wastewater is discharged into the ring trough of the upper part of the frame.

As the level of the fluidised coal layer rises to the overflow, the spent suspension enters the thickener and is then sent for desorption. Sorption purification can be regenerative, when the extracted substances are utilised, or destructive, when the extracted substances are destroyed, simultaneously losing 5–10% of activated carbon. After sorption treatment of wastewater from fish processing enterprises, a destructive (thermal) method of activated carbon regeneration is usually used. Activated carbon costs account for up to 30% of the cost of sorption treatment. In the practice of wastewater treatment in the fishing industry, activated carbon is used in the post-treatment of brine after thermal or physicochemical treatment, where the static activity of the adsorbent is used, as well as in the system of recycled water consumption of wastewater from the cooling of canned food directly in autoclaves. There, the dynamic activity of the adsorbent is used.

9.1.2. Recirculating wastewater consumption in certain food production processes

With the growth of production, technical equipment of enterprises and increased sanitary requirements, the total water consumption is increasing. Accordingly, wastewater discharge is also increasing. The main direction for reducing their volume is rational water consumption, compliance with technological regimes, reuse and recycling of water.

In the technological process of cooling canned food directly in an autoclave, waste water can be sent for reuse without prior gel purification, for example, for washing raw materials and containers, and defrosting products. Waste water from fish processing is often used to transport fish waste.

Recycling of water in the MP-3 fish washing machine

The water recycling system includes a special filter-settling tank, which is a rectangular tank with a sloped bottom, divided by a partition into three compartments, where water is filtered and sediment is collected at the bottom. There are grates at the top of the partition. The water that fills the first

compartment flows into the second, and from there into the third, from where it is pumped out and fed back into the machine for reuse. At the end of the washing process, the water is discharged into a special container for further treatment or directly into the sewer. The fish is loaded into the washing machine from the end side B, moves along the bath and enters the conveyor B, where it is finally washed with jets of clean water A using an irrigation device.

Recycled water consumption can be organised in a number of other technical processes: when salting fish with brine, when cooling canned food directly in autoclaves, when defrosting fish in spray defrosters, and when cooling refrigeration machine compressors.

Recirculation of brine from brine salting of fish

In the production of salted, smoked and dried fish, as well as in canning, solutions of table salt (brine) are used for salting fish. They are reused many times, especially in mixed salting lines for small fish from the Azov-Black Sea basin (anchovies, sprats). As the brine is reused, its colour changes from cloudy pink to cherry brown. They become cloudy due to the removal of organic substances (protein and fat) from the fish, as well as mechanical contamination in the form of scales, pieces and fibres of fish tissue, etc.

Brine that has been used repeatedly has an unpleasant smell of oxidised fat, alkaline or acidic. Their suspended solids content can be 500–6400 mg/dm^3, nitrogenous substances – up to 3000 mg/dm$^{(3)}$ ·of which 30–40% are protein substances, fat – 120–20,500 mg/dm^3, and COD – 6,300–14,500 mg O_2/dm^3. Further use of such brine is impossible without compromising product quality.

As the medium in which fish is salted, the brine largely reflects all the changes that occur in the fish during salting. The composition of the brine, its physical and chemical properties change. Usually, the deterioration of brine during repeated use begins earlier than the deterioration of the fish itself, so timely replacement of poor-quality brine with freshly prepared brine can prevent fish spoilage. It is therefore important to monitor the quality of the brine, which is determined by both organoleptic (colour, smell, turbidity) and physicochemical methods. It has been established that the deterioration in the quality of brine is caused, in particular, by a decrease in the aggregate stability of the colloidal protein system, i.e. their transition from a soluble state to an insoluble state – a suspension. The loss of protein solubility in brine is often irreversible.

The aggregate stability of proteins in brine is influenced by a high concentration of table salt.

Microflora develops in brines, and the weaker the concentration of table salt, the higher its content, which is 104–106 CFU/cm^3 and above. The presence of protein suspension leads to an increase in microorganisms. If the brines are benign, the content of microorganisms in filtered and unfiltered brines is approximately the same. As the quality deteriorates, the difference in the content of halotolerant forms increases 50-100 times in unfiltered brines. As the quality deteriorates and the amount of coagulated protein in the brine increases, the growth of proteolytic and putrefactive forms of microorganisms increases.

If the brine is of questionable quality in terms of organoleptic and physicochemical indicators, it should be removed from the production process. It cannot be discharged directly into the sewer system, let alone into a water body, so the factory treatment plant system must include averaging tanks for diluting brine with other wastewater, with a dilution threshold of up to 50. In addition, brine contains 15-20% table salt, and it is not economically viable to discharge it with wastewater.

The quality of brine can be improved by reducing the activity of physicochemical processes and decreasing the content of organic substances in it, which requires brine regeneration. Thus, brine regeneration is necessary to extend its useful life.

The following methods of brine purification have been tested: electrochemical, physicochemical, thermal, and membrane.

The electrochemical method proved unacceptable, although it achieves almost complete removal of all protein substances from brine. The optimal mode of electroflotocoagulation purification is as follows: current density 5 mA/cm^2, process duration 10 minutes, settling time 30 minutes. This treatment provides 94% purification of suspended substances and 92% purification of ether-soluble substances, while producing up to 4% foam from the brine mass. The purified brines are completely transparent, yellowish in colour, with a pH of 4.5–5.0, and complete sterility is achieved. However, brines have an excessive active chlorine content (up to 26–81 $mg/dm^{3)}$, a chlorine odour, and the formation of chloramines and other by-products of electrolysis.

In addition, when the treatment of brine with a direct current of 2.5 A is stopped, the chemical processes do not stop: the pH of the brine decreases to 1, and after 10–15 days of storage, a bitter almond odour is noticeable.

Physical-chemical and thermal methods with additional purification using activated carbon or ultrafiltration are quite effective.

Physical-chemical method

The physical-chemical method of purification is based on the precipitation of protein substances present in brines in a colloidal and dissolved state using chemical reagents.

The brine treatment technology includes the following operations. First, caustic soda in the form of a 50% aqueous solution is added to the brine until a pH of 9.3–9.5 is reached, thoroughly mixed, and allowed to settle in a vertical settling tank for 12–24 hours. The sediment is drained, and the settled brine is treated with a 30% hydrochloric acid solution, bringing the pH of the medium to 6.1–6.4, and settled again, and the resulting sediment is drained. The yield of purified brine is 70–75% of the initial amount. After such purification, the brines become transparent, yellow in colour, odourless, and bacterial contamination is reduced by 70–100 times. However, non-protein nitrogenous substances account for up to 60–70% of the total nitrogen content in brine and are not removed during physical and chemical treatment; they are a good breeding ground for microorganisms.

These brines are suitable for use immediately after purification, but cannot be stored because they spoil quickly. To ensure the preservation of brines in the inter-process period, additional purification is necessary.

Thermal method

The brines are placed in cylindrical containers with a conical bottom, equipped with a steam jacket, and heated for 10–15 minutes at 105 ^{0}°C. The proteins denature and, when settled, precipitate as flakes. The sediment is drained; it contains 63–65% moisture, up to 10% protein and up to 25–27% table salt. This sediment can be used as an additive in animal feed.

After boiling, the brine loses its unpleasant odour and microorganisms are almost completely destroyed. As with the physical-chemical purification method, the thermal method does not remove non-protein nitrogenous substances from the brine, which are a good breeding ground for microorganisms, so after purification it cannot be stored for long, but can be successfully used for salting fish immediately.

Non-protein nitrogenous substances can only be removed after additional purification by sorption or ultrafiltration.

Sorption method of brine purification

Powdered activated carbon is added to the clarified brine in an amount of 0.75 – 1.0 % of the brine mass and stirred for 15 – 20 minutes. The activated carbon is separated by filtration, and the brine is treated a second time by adding activated carbon in an amount of 0.25% of the brine mass. After such treatment, the brine has no odour or colour, the non-protein nitrogen content is reduced by 35%, and it is chemically and bacteriologically safe and can be used for salting fish. To prevent the development of halophilic microorganisms during long-term storage of brine, it is treated with hydrochloric acid, reducing the pH of the medium to 5.2–5.5. In this form, brine can be stored for six months in open rooms protected from the sun and atmospheric precipitation and remains suitable for salting fish.

The purification methods are simple in terms of equipment, using traditional chemical reagents, and activated carbon can be regenerated by calcination at a temperature of 300–400 ^{0}C, followed by rinsing with clean water.

Ultrafiltration purification of brine pits

Ultrafiltration is the simplest method of deep purification of brine ponds.

Various polymers are used in the manufacture of ultrafiltration separation elements. Acetate cellulose membranes of the UAM-150, UAM-300, and UAM-400 types with pore diameters of 150, 300, and 400 A, respectively, copolymer and polysulfonamide membranes using BTU-0.5/2 type tubular elements have been tested. The selectivity of the membranes to table salt averages about 2%.

Ultrafiltration is preceded by cleaning the brine by settling for 24 hours, followed by filtration through metal sieves with a mesh size of 0.5–1.0 mm.

The following brine treatment mode is recommended: flow rate in the

system – 5 m/s, pressure – 0.3 MPa, temperature – 15–30 ^{0}°C with a table salt concentration of 12–16%. At higher concentrations of table salt in the brine, the permeability of the membranes decreases. It also decreases during operation, so every 6–8 hours of operation, the membranes are restored by washing with water, mechanically, with chemical reagents, and disinfected.

For brine regeneration, it is recommended to use UAM-400 type acetate cellulose membranes (pore diameter 400 A) or copolymer membranes, which provide a permeability of 50 dm^3/m^2per day with high separation efficiency. The selectivity of these membranes for suspended solids is 100%, for total nitrogen – 33 – 45%, for protein – 72 – 100 %, for fat – 95 %, volatile nitrogenous substances – 32 – 56 %, lipid oxidation products – 42 – 60 %. Purified brines are transparent, their light transmittance is 98 – 100 %, they are colourless (or slightly yellowish) and odourless. Total bacterial contamination and salt-resistant microflora are represented by isolated specimens. The yield of regenerated brine reaches 96 % of the initial volume.

9.2. Utilization of waste from fish processing wastewater

9.2.1 Waste disposal at local treatment facilities

During fish processing, many production stages involve the use of water into which pieces of fish, scales, fat, oil, tomato sauce, grains and many other substances are discharged. Initially, the quality of this waste is similar to that of the raw materials and semi-finished products, so it is advisable to separate it from the wastewater as soon as possible. To achieve this, production flowcharts for the main types of fish products must include dedicated units that, on the one hand, collect valuable waste and, on the other, reduce the concentration of pollutants in the wastewater discharged to the plant's treatment facilities.

Waste disposal in the production of feed meal by pressing and drying

During the production of feed meal from fish waste by pressing and drying, a press broth is formed, the amount of which, depending on the raw materials used and their degree of freshness, can range from 50 to 70% of the mass of the raw materials sent. Its dry matter content can reach 10-30%, water-soluble protein and suspended particles – up to 10%, fat – up to 29%, non-protein nitrogen – 0.5–0.8%, amino acid nitrogen – 0.2–0.7%, pH of the medium – 6.3–6.7.

In the pre-pressed broth, the protein part can be in the following dispersed state:

- a coarse suspension consisting of large particles of boiled fish mass passing through the press screen;
- A thin suspension, insoluble in water, which has aggregate stability due to the positive charge characteristic of denatured protein particles in an acidic environment, from a group of proteins resistant to short-term heating.

Nitrogenous substances are 30–35% represented by protein breakdown

products that cannot be separated during mechanical processing, many collagen-like substances (up to 20% of total nitrogen). Fat in the broth is distributed in the form of a stable emulsion, the stability of which is due to the presence of suspended calcium proteins.

The technological scheme for processing pre-pressed broth provides for the removal of coarse impurities using a sedimentation centrifuge, which works as follows. The pre-pressed broth is fed through a movable feed pipe into the rotating rotor unit, where centrifugal forces separate dense particles (sludge) from the broth, which are driven from the inner surface of the conical drum by a screw conveyor to the solid particle dewatering section. Then, through an opening, the dense particles enter the cavity of the casing and are removed from the centrifuge through a pipe. The liquid part of the broth, together with the fat, is separated from the dense substances under the influence of centrifugal force and is removed from the centrifuge through four openings regulated by face plates and then through a pipe. The mass of the sludge formed can reach 5% of the mass of the broth at a moisture content of 60%. It is sent for drying to obtain feed fish meal.

The fat-containing clarified broth is sent to a mud separator to extract the fat and thus obtain defatted broth.

The broth is separated in the separator drum according to the principle of thin-layer separation with continuous removal of fat and defatted broth and periodic discharge of sludge.

Heated to 90–95°^{0}C, the clarified pre-pressed broth is discharged through a central pipeline into a hollow shaft and through openings in the plate holder enters the working chamber with a set of conical plates rotating at high frequency. Under the action of centrifugal forces, dense particles are thrown with some water to the periphery of the drum and removed from it through periodically opening nozzles into the body cavity. Fat, as a light fraction, moves to the centre due to the conical shape of the plates and is discharged from the fat space through the upper side windows. The defatted broth (heavier fraction) moves along the plates to the periphery and is removed from the broth space through other openings. Sludge gradually accumulates in the separator's sludge tank and is periodically unloaded. At this time, the supply of broth for clarification is stopped.

The start and stop of the broth supply, as well as the separated fractions, is carried out by a special automation system.

The fat is cleaned of broth residues in the ISA-3M fat separator. The fat is fed for cleaning at a temperature of 85–90°^{0}C, and the water at 95–100°^{0}C. Water consumption is 15–20% of the weight of the cleaned fat.

The main working part of the ISA separator is a drum that is set in rotary motion. Untreated fat enters the distributor through a pipe and spreads across the spaces between the plates. The upper solid plate acts as a separating device for the drum. Under the action of centrifugal force, particles heavier than fat (e.g. water) are thrown to the periphery of the drum, and the heaviest solid impurities settle on the inner walls of the drum. Water and some of the small solid particles form a middle layer, which rises between the drum cover and the upper plate, enters the receiving chamber through the water outlet pipe and is removed to the outside.

The purified fat, located closer to the center of the drum, forms the inner layer and enters the receiving chamber and, through the fat outlet pipe, is drained into the receiving container. After 4-5 hours of operation, the separator is stopped for cleaning.

The defatted broth is evaporated to a concentration of 30–50% in vacuum evaporators, with the evaporated broth then being used either as a standalone feed product or to obtain "whole" feed meal. In the latter case, the evaporated broth is dried together with the dryer. However, at most enterprises and vessels, the use of broth is limited to the separation of sludge and fat, and the defatted or non-defatted broth is drained into the sewer. This is due to a number of reasons: the lack of evaporation units, the difficulties of their operation, and their high energy consumption.

With the low productivity of fish meal plants, the cost of operating evaporators is not recouped due to the relatively small increase in feed meal yield from the use of evaporated broth (1–2%).

The operation of evaporators is economically feasible only if the productivity of fat removal plants is at least 100 tonnes per day of raw materials. Therefore, other methods of concentrating press broths are being sought, for example, using ultrafiltration. This method is widely used in the food industry in the production of high-quality sugar, pasteurisation of beer, stabilisation of grape wines, processing of milk to obtain basic dairy products, and concentration of fruit and vegetable juices.

Dehydration of broth by ultrafiltration is carried out without phase transformations and usually occurs at ambient temperature. The equipment used for this is less energy-intensive than for evaporation. Protein concentrates are obtained without changing the initial properties of nitrogenous and other substances.

The most promising devices for ultrafiltration of food liquids are filter presses, which are based on a filter element consisting of two membranes placed on both sides of a flat support plate on a drain. The support plates are located at a short distance from each other (0.5–5 mm) and form a membrane space for the solution being separated. These devices are characterised by their simplicity of manufacture and assembly, the possibility of quick replacement of membranes, and ease of installation and operation. At the end of the service life of the membranes in the devices, only the membranes are replaced, which significantly increases the economic performance of such installations.

The first experiments were conducted on sub-press broth during krill processing at the Akademik Knypovich processing plant. Before use, the broth was filtered through a metal mesh with a hole diameter of approximately 1 mm. The concentrate was obtained on flat-frame ultrafiltration modules of the filter press type, using cellulose acetate with pore sizes ranging from 40 Å (UAM-50) to 450 Å (UAM-500) as membranes. During ultrafiltration, the pressure at the system inlet was maintained at 0.37–0.39 MPa, and at the outlet – 0.24–0.26 MPa. The filtrate productivity, depending on the pore size of the membranes, was 0.5–15.5 $dm^3/(m^2 \cdot h)$. The work carried out has demonstrated the feasibility of using

this type of apparatus with UAM-150 and UAM-200 membranes, which have a filtrate productivity of 9.7–11 $dm^3/(m^2 \cdot h)$ and ensure a low (4.2–4.8%) dry matter content in the filtrate. The concentration process is stopped when the dry matter content reaches 30–32%.

The UAM-200 membrane is considered the most suitable for concentrating krill press broths. The use of membranes with larger pore sizes (UAM-400 and UAM-500) leads to an increase in the content of non-protein and polypeptide nitrogen in the filtrates due to the passage of larger molecules of non-protein nitrogenous substances.

The initial productivity of UAM-200 membranes was 10.2–11.2 $dm^3/(m^2 \cdot h)$ per filtrate, and the average concentrate yield was 23.6% of the initial broth volume. All protein substances and lipids contained in the initial broth remained in the concentrate, while non-protein nitrogenous and mineral substances passed into the filtrate. In the broth concentrate, the content of protein substances increased 2.4 times, and lipids increased 3 times compared to the content of these components in the initial broth.

During the concentration of krill pre-pressed broths by ultrafiltration, there was no destruction of protein substances, as evidenced by an increase in the content of protein nitrogen by 1.8 times (relative to total nitrogen) and polypeptide nitrogen by 1.1 times compared to the content in the pre-pressed broth. During the concentration of krill broth by traditional evaporation, the destruction of protein substances was observed by almost 2.4 times, and polypeptides by 3.2 times compared to the content of these substances in the original broth.

When concentrating pre-pressed broths by ultrafiltration, the processes of lipid oxidation are insignificant, but when evaporating them, the amount of peroxide compounds increased 6 times, secondary oxidation products – 1.8–3 times, and the degree of lipid unsaturation decreased by 1.4 times compared to similar indicators for lipids in pre-pressed broths. In terms of the qualitative composition and quantitative content of individual amino acids, the protein concentrate obtained by ultrafiltration remains practically at the level of the initial pre-pressed broth, while in the concentrate obtained by boiling, the content of essential amino acids decreased by 8.6%, and that of non-essential amino acids decreased by 6.6%.

Thus, the protein concentrate obtained by ultrafiltration is a more complete product than the evaporated broth. Krill broth concentrates with a moisture content of 70.5% contain (in %): protein – 12.8; lipids – 9.9; non-protein nitrogenous substances – 0.95; minerals – 2.4. They have a bright pink colour and a smell characteristic of crustacean paste. Such concentrate can be used as an independent feed product. To extend its shelf life, it is preserved with sodium sulphite (at a dose of 1.8%). When the concentrate is added to the pomace before drying in an amount of 12% of the raw material mass, the yield of krill meal can be increased by 4%. At the same time, krill meal will contain 4% more nitrogenous substances compared to meal obtained without the use of pre-press broth.

Similar results were obtained by other researchers when using acetate

cellulose membranes in experiments with press broth formed during the pressing of boiled fish raw materials. The content of dense substances in the protein-lipid concentrate reached 35–38%, and the content of nitrogenous substances reached 16–20%. The amino acid composition data also confirm the high feed quality of the concentrate.

However, the use of cellulose acetate membranes has significant drawbacks: shrinkage of membranes due to their soft structure under pressure, clogging of membranes due to the formation of protein-lipid deposits on their surface, which have particle sizes close to the size of pores.

Thanks to improvements in membrane manufacturing technology, it has become possible to use a new generation of metal-ceramic membranes based on titanium. Such membranes can be used to treat solutions with temperatures up to 400 ^{0}°C in a pH range of 3 to 12. This makes it possible to send the pre-pressed broth to ultrafiltration immediately after its separation at a temperature of 80–90^{0}°C. This ensures the continuity of the process and its higher efficiency. The membrane manufacturing technology allows for a highly uniform structure of the selective layer, which means that the technological parameters of the ultrafiltration process can be selected with a high degree of accuracy.

Preliminary experiments were conducted on the concentration of fish press broth on Trumm™ metal-ceramic membranes with pore diameters of 0.4, 0.2, 0.1 and 0.05 micrometres under a pressure of 0.15–0.17 MPa for a duration of 3 hours. It was found that the selectivity of membranes for dry substances, volume and non-protein nitrogen varies and is inversely proportional to their pore diameter. While for membranes with a pore diameter of 0.4 μm it is 40.4, 28 and 37%, respectively, for membranes with a pore diameter of 0.05 μm these indicators are significantly higher and amount to 62.89 and 76%. These membranes have significantly higher permeability. If after 3 hours of operation it decreased by 36.5%, then in membranes with a pore diameter of 0.4 μm – 10 times. These data allowed the authors to conclude that it is advisable to use membranes with a pore diameter of 0.05 μm.

During the experiments, the content of dense substances in the concentrate increased by 1.47 times, fat by 1.6–3.5 times, and nitrogenous substances by 1.15–1.2 times, i.e. the separation capacity of the membranes is low, and the work is planned to continue in the direction of selecting membranes with a smaller pore diameter.

Obtaining protein concentrate from defatted pre-pressed broth by direct drying

Specialists from the Riga Refrigerated Fleet Base, together with employees of the Institute of Biology of the Latvian Academy of Sciences, conducted research on the direct drying of clarified skimmed press broth without preliminary evaporation in a dryingcrushing unit, which is used in the dairy industry to obtain dry milk. The installation for drying press broth consists of: a tank for storing press broth, a dispensing tank, a drying and crushing unit of the SDA-250 type, three transfer pumps, a broth mixer, a magnetic filter, an antioxidant dispenser, a preservative dispenser, a mill-crusher, a storage hopper, scales, and a bag sewing

machine.

The concentrate is obtained as follows. The broth flowing out from under the press of the fat-flour installation is pre-clarified and degreased, and then collected in a storage tank. The broth is preserved with sodium pyrosulphite, which is introduced through a pipe. As it accumulates, the broth is pumped from the storage tank to a dispensing tank equipped with a heating system.

There, the broth is heated to 90 ^{0}°C and sent to the SDA-250 unit. To prevent dry substances from sticking to the steam-heated coils in the discharge tank, a broth mixing system is organised, which includes a mixer where the broth flows from two levels of the discharge tank, is mixed and fed back into its upper part.

The SDA-250 unit consists of two hollow cylindrical rollers made of special cast iron. The outer surface of the rollers is carefully ground and polished. The ends of the rollers are closed with removable covers and trunnions. Some trunnions are solid with a fixed drive gear, others are hollow, and through them saturated steam is introduced and the resulting condensate is removed (through a siphon pipe). The steam pressure in the rollers is 0.4–0.6 MPa. The broth is dried at a temperature of 130–150 ^{0}°C.

The broth is fed either into special troughs or into the space between the rollers. Discs are fixed in the troughs on horizontal shafts. When the rollers rotate (0.016–0.08 s^{-1}), they periodically immerse themselves in the product and become covered with a layer of broth. In the upper part, opposite each disc, there is a tube with a nozzle, into which air is supplied from a high-pressure centrifugal fan. The air blows the broth off the discs and carries it in a sprayed state to the surface of the rollers. Knives are installed under the spraying zone to remove the dry film. In the second option, the broth is fed onto the rollers from above through a spray device. The water from the broth evaporates and a crust of dry substances forms on the surfaces of the rollers in one revolution, which is removed from the rollers in the form of a thin film, and the evaporated moisture is sucked out by a fan.

The dried product is fed through screws into a grinding mill and, in the form of flour, into a storage bunker, where an antioxidant is added.

The flour is packaged after separating metal impurities on a magnetic separator into bags with a polyethylene liner by weight (20–30 kg). Fish meal obtained in this way is a protein product containing no more than 8% moisture, 0.5–1.75% fat, and 76% protein, i.e., it is a protein concentrate. In terms of the quantity and composition of macro- and microelements, free amino acids and other biologically active substances, it is not inferior to protein concentrates obtained from fish meat. The yield is 9–12% of the initial broth.

Protein concentrate can be used as a protein supplement in feed for farm animals and poultry or in small amounts (0.20–0.25%) in the diet of chicks to stimulate their growth. When protein concentrate is added to the diet of chickens in an amount of 0.2–2.0%, their growth is stimulated by 10–11% with a simultaneous reduction in feed consumption by 8%. When 1% concentrate is added to the feed of laying hens, egg production increases by 16% and egg weight increases by 3%. Adding 1% protein concentrate to the diet of fattening piglets leads to a 10–28% increase in their live weight gain and an 11% reduction in feed

consumption per 1 kg of gain. Adding 1 tonne of concentrate as a biostimulant to poultry feed will result in an additional 6 tonnes of live weight of broiler chickens. This line was first tested at the Trudova Slava floating base of the Riga refrigerated fleet.

Extraction of valuable substances from pre-pressed broth using the pressure flotation method

One of the fish processing plants tested a unit for processing defatted broth using pressure flotation (at a pressure of 0.39 MPa in the saturator), collecting the foam mass and then drying it. Its operation provides an additional yield of feed meal of 0.3% of the initial raw material (or 2% of the meal yield).

For more complete separation of suspended solids before flotation, it is recommended to treat the broth with alumina $A1_2(SO_4)_3$ in the form of a 2.5% solution or calcium chloride at a dose of 0.5% at pH 4.5. This method not only increases the flour yield, but also achieves up to 98% efficiency in purifying the broth of suspended substances and fat.

Polysaccharides are sometimes used as flocculants, for example, sodium carboxymethylcellulose at a dose of 0.6–0.5% or polyacrylamide at a dose of 1% by weight of the broth. Flocculants are added in the form of a 10% solution. After mixing with the pre-pressed broth and holding to complete the coagulation and flocculation process, the dense substances are separated in a sedimentation centrifuge. This treatment increases the flour yield by 2.7 and 4%, respectively.

The liquid separated from the protein-fat mass can then be thickened by ultrafiltration, which will allow the removal of low-molecular-weight peptides and free amino acids that do not precipitate with reagents from the clarified broth. The concentrates obtained can be used in the medical and microbiological industries.

Usually, the fat separated from the press broth is of low quality and is sold mainly as technical fat and «batak». A separate fish processing plant uses a fat purification scheme based on refining. The separated «batak» fat enters a fat collector, from where it is pumped into a hydrolyser, where it is purified. The refining of «batak» involves mild alkaline hydrolysis with a highly concentrated alkali solution (neutralisation) followed by washing with a salt solution (destruction of pigment substances).

The entire process is carried out at a temperature not lower than 94 ^{0}°C. This fat is then separated to remove protein and water. The resulting fat corresponds to semi-finished veterinary fat in terms of its organoleptic and chemical properties. It is then fortified with vitamins A and D to the standard content, packaged in glass containers or metal barrels and used as a feed additive for farm animals.

Preservation of press broth to extend shelf life

With a domestic press-drying plant operating at a capacity of 35 tonnes per day in three shifts, 17–24 tonnes of press broth are produced. It can be sold as animal feed without prior concentration. Since press broth is a perishable product, it must be preserved. One such method is incomplete alkaline hydrolysis.

The pre-pressed broth is first degreased to a residual fat content of 4%.

During alkaline hydrolysis, some protein groups break down into intermediate products – polypeptides and peptides (incomplete hydrolysis), while others break down into end products – amino acids (complete hydrolysis).

The technology for obtaining hydrolysate from press broth by incomplete hydrolysis is as follows. A concentrated solution or crystalline caustic soda is poured into a container installed near the fat and flour workshop in an amount equal to 2.5% of the volume of broth poured into the container. Then, the press broth is poured into the container and everything is thoroughly mixed. The mixture is heated with dry steam for 40 minutes at a temperature of 85–90°^{0}C, and then kept for another day without heating (at a temperature of 20–25°^{0}C). The resulting hydrolysate of pre-pressed broth (HPB) can be stored without changing its chemical properties at ambient temperature for up to two years. Cooling HPB to 0°^{0}C and below leads to the formation of jelly due to the presence of gluten in the broth, a product of collagen breakdown.

HPB has surface-active properties and can be used as an emulsifier for obtaining bitumen emulsions, drying oil emulsions for oil paints, as well as a detergent for cleaning tanks on ships transporting fish oil from grease contamination. The emulsifying capacity of hydrolysates is very high. Thus, stable bitumen emulsions can be obtained by direct short-term mixing of the components.

GPB can be transported in steel containers by both road and rail.

Disposal of waste generated during fish frying in steam oil frying ovens

It is known that during the frying of fish in steam oil frying ovens, pieces or crumbs of fried fish, breadcrumbs, etc. accumulate at the bottom. This waste is partially removed with a water cushion during the frying process, but the bulk of this waste is discharged into the sewer system during oven cleaning in cases of single or double shift operation of the workshop. During the draining of the "water cushion" before washing the oven, vegetable oil is partially discharged along with solid waste. All this waste, called fat mass, ends up in the factory's treatment facilities, complicating their work, even though it has high feed value. It can be captured in a specially designed installation. The installation consists of a primary settling tank, a storage tank and a secondary settling tank.

The unit works as follows. During the cleaning of the roasting oven, water together with fat mass enters the primary settling tank through a pipeline via a gate valve, with the valve open and the stopcock closed. If the roasting oven is located on the second floor, the fat mass flows into the primary settling tank by gravity; if it is on the first floor, pumping with a pump should be provided.

After 5-6 hours of settling in the primary settling tank, the wastewater separates into three layers: oil, water, and a dense part, which is the main part of the fat mass.

First, water is removed from the primary settling tank by opening the valve and increasing the pressure in the settling tank to 0.12 MPa. Then the valve is opened and, since the end of the intake pipe is always in the water layer with the

help of a float, the water under the pressure of compressed air flows through the pipe and valve into the secondary settling tank, and then, after additional clarification, flows into the sewer. At the same time, the pressure gauge readings and the composition of the discharged water are monitored. If grease begins to come out of the drain pipe, the valve is closed and the water drainage operation is stopped.

After draining the water, the degree of filling of the sedimentation tank is determined by the pointer and scale. The transfer of grease to the accumulator is also carried out using compressed air, but at a pressure of 0.15 MPa. The valve and gate are opened, and the grease from the primary sedimentation tank enters the accumulator, after which the gate is closed again. It is recommended to treat the grease in the storage tank with a preservative – table salt or sodium thiosulphate. For better mixing, the preservative is poured into the empty storage tank through the hatch before loading the grease from the primary settling tank.

The fat mass is also unloaded from the storage tank into a tanker truck using compressed air. To do this, the hose from the storage tank is attached to the hatch of the tanker truck, the valve is closed, and compressed air is supplied to the storage tank through the adjacent valve. The pressure in the storage tank rises to 0.15–0.16 MPa, which is recorded by a pressure gauge. When the set pressure is reached, the valve opens and the grease is transferred from the storage tank to the tanker, after which the valve closes again. A separate valve is used to blow out the pipe. When the accumulator overflows, the excess grease mass is discharged into the secondary settling tank using a device. The float mechanism is adjusted so that the end of the intake pipe is in the water layer at any position of the float and at any level of mass in the primary settling tank.

After the fat mass has been transferred, the primary settling tank is washed with hot water using a shower-type device, with the wash water draining through a cork tap. The accumulator is washed with hot water using a hose through the neck. The washings are removed through a valve with hot water from the hose.

The average yield of fat mass is 10–12 kg/tube of canned fried fish. The average chemical composition of fat mass in %: dry matter – 28, fat (oil) – 15, protein – 2.3, carbohydrates – 10, minerals – 1. One kilogram of such fat mass contains 0.53 feed units and is used as a supplement for feeding young cattle and pigs.

Disposal of waste generated during the formation of meatballs and meatballs on a meatball machine

In the production of canned meatballs and meatballs in tomato sauce, the process of forming meatballs and meatballs is carried out on an AT-61 meatball machine of the Yegorov system. During the forming process, drinking-quality water is used to flush the machine. In the process, it becomes contaminated and is discharged to the factory's treatment facilities. The hourly discharge of such water is 0.12–0.43 m^3, with an average of 0.33 m^3. The time coefficient of unevenness is 1.3, and the specific water consumption is 0.32 m^3 per can of canned food.

The wastewater has a fresh fishy smell. Its temperature does not exceed 35

^{0}°C, the average pH of the water is 6.7, and it has the following chemical composition (g/dm³): suspended solids – 15.8; dry residue – 9.2; total nitrogen – 2.6; fat – 6.3; **BOC**$_{full}$ – 12.4; **COD** – 24.2.

Thus, the loss of valuable substances with wastewater is quite significant and must be utilised.

Wastewater from the teff machine flows by gravity into a special container. It can be stored without prior treatment for 4 hours after heating for 15 minutes at 80 – 85 ^{0}C – 8 hours.

Waste can be concentrated by settling or centrifugation. When settling wastewater for an hour, it is possible to separate up to 25.6% of the wastewater volume at 92% humidity. When settling wastewater preheated at 80–85°^{0}C for 15 minutes, the sediment yield increases to 35% at the same humidity. When centrifuging for 15 minutes at 8000 rpm of wastewater preheated to 85°^{0}C for 15 minutes, the sediment yield is 20% at a moisture content of 60%.

When collecting protein-fat mass from a feed machine by settling preheated wastewater, a system of settling tanks can be used, which is accepted for collecting fat mass from roasting ovens. The collected mass can be used as a feed additive, then, to extend the storage period to one month, it should be preserved with low molecular weight fatty acids – LMFA (with no more than 6 carbon atoms) at a dose of 0.5–1.0% or used to produce feed meal using a pressing and drying scheme. The flour yield will be 0.7–1.0% of the weight of the wastewater with the following chemical composition (%): moisture – 10, fat – 12.5, protein – 72.9, minerals – 4.5.

Disposal of wastewater from fish blanching

Local wastewater treatment should be provided for in the technological operation – fish blanching. *Blanching* refers to the short-term heat treatment of fish in water, oil, salt, vinegar-salt solution using steam or hot air, ultra-high frequency electric current and infrared rays. Combined treatment may also be used. Under the influence of heat, proteins coagulate, releasing moisture from the fish, along with protein and fat substances. The amount of broth produced from fish depends on its type and condition, as well as cooking conditions, and after 20–30 minutes of processing, it accounts for 10–20% of the fish's weight. The greatest loss of mass is observed with microwave blanching, amounting to 21.5%, followed by steam blanching – 21%, then oil blanching – 16%, salt solution blanching – 14%, and hot steam blanching – 12%. Frozen fish releases more protein than fresh fish of the same species, and fish cut into pieces releases more than whole fish. Lean freshwater fish loses the most broth during blanching. The broth released during fish blanching contains 5-7% dry matter (up to 10% in salt solution), consisting mainly of protein and fat. The broth can be evaporated to a residual concentration of 30% for storage or used without evaporation within two hours of obtaining it after heating to 75–85 °C as a filling for canned food, for example, canned fish soup.

Egg white can be replaced with this broth in some types of culinary products. For example, chilled broth is whipped in a mixer until foamy and used to make

fish soufflé. The soufflés look the same, but taste better than the control samples.

Due to the presence of technical steam condensate containing contaminants in the broth, it cannot be used directly for food purposes when blanching fish with hot steam or a steam-air mixture. It must be further processed, for example, to obtain fish protein concentrate. For this purpose, the broth is alkalised with caustic soda to pH 10–11 and kept for 45 minutes with constant stirring. The resulting sediment is filtered out, and the remaining alkaline solution is acidified to pH 5.5. This causes the protein-lipid complexes to precipitate, which are then filtered out. The separated precipitate is treated with a mixture of ethyl alcohol and trifluorotrichloroethylene, which leads to the separation of protein and fat. The proteins are separated by filtration, washed with ethyl alcohol to remove trifluorotrichloroethylene, and dried under vacuum to a moisture content of 10–12%. In addition, by adding lactic acid bacteria to the broth after its fat content has been normalised, a substitute for whole milk can be obtained for feeding young cattle and pigs.

Disposal of waste generated during the salting of anchovies and tulka on mechanised lines

When salting anchovies and tulka on mechanised mixed salting lines, the brine is reinforced in the salt concentrator, for which it is collected in a special settling tank and then pumped into the salt concentrator. Foam accumulates on the surface of the brine in these settling tanks, which is raked off with a special skimmer and placed near the container.

With daily disposal of such foam mass, the acid number of the fat contained in it does not exceed 7–11. It contains 26–53% moisture, 50–65% fat, 1–4% protein, and 7.7–16.5% minerals. Of these, table salt accounts for 7.6–16.4%. The fatty acid composition of the fat in the foam mass is mainly monounsaturated (oleic 18:1) acid – 45.6–49.8% and polyunsaturated fatty acids (PUFA) – 25.3–34.4%, among which tetraenoic acids (20:4) dominate – 7.2–10.1%. The fractional composition of foam mass fat is mainly represented by triglycerides – 68–75%, phospholipids – 6 – 7%, and colourants – 2–2.5%.

Industrial equipment for extracting fat from foam mass has been tested – an OGSh-321 K-5 sedimentation centrifuge, and for fat clarification – an ISIM-222 separator. When using a sedimentation centrifuge with foam mass heated to 75°^{0}C, up to 52–57% of fat can be extracted. After separating the fat heated to 90 ^{0}°C, it is possible to extract up to 65% of the original content in the foam mass in pure form with an acid number of 6.5–8.8 and a peroxide number of 0.2–0.3%. In purified fat, the iodine number is 136–142, the saponification number is 160–171, and unsaponified substances are 1.9–2.3%. This fat meets all the requirements for grade II technical fat, which can be used for technical purposes or further processed to obtain veterinary fat. In the latter case, the fat is neutralised using sodium phosphate or gaseous ammonia. After neutralisation of free fatty acids, the fat is washed with water or a 1% solution of table salt to a neutral reaction and dried in a stream of carbon dioxide. Fat losses during neutralisation are 10–15%, and the acid number of the fat is reduced to 1.2–1.9.

After normalisation with vitamins, such fat can be successfully used as veterinary fat.

In addition to fat, centrifugation of the foam mass produces a dense sediment, which accounts for up to 25% of the initial mass. It contains 39–49% fat and 3.5–5.2% protein. This product can be used for feed purposes.

Disposal of scales

Scales enter wastewater during the operation of machines that remove scales, when unloading anchovies and tulka as fish pulp using fish pumps or vacuum transshipment devices.

The scales of some fish contain a significant amount of guanine, a semi-finished product of pearl pat. These include herring, sardines, anchovies, etc. The approximate yield of guanine from the scales of these fish is 5–10%. With an average scale content of 2% of the fish weight, up to 20 kg of scales can be collected from each tonne of fish processed, yielding 1–2 kg of guanine. Collecting scales is not particularly difficult and can be done by passing the wastewater generated during fishing, washing fish, and removing scales with special scaling machines through special scale-catching devices.

For example, a scale separator in the form of a rotating mesh drum. Water together with scales flows into the drum, passes through the drum mesh into a tray, and the scales remaining on the mesh are blown by air from a fan into a special container. After collection, the scales must be thoroughly washed with water and preserved with salt or cold. The salt dose for salting scales is 20%, and the scales are frozen to -18 ^{0}°C. Before removing guanine from fresh or frozen scales, they are salted with a dose of table salt of 15-20%. After two days of salting, the scales are poured with kerosene in a container with a stirrer. Stir for 20–40 minutes and drain the resulting guanine suspension in kerosene through a filter into a settling tank, then pour a new portion of kerosene over the scales and repeat several times until the guanine is completely removed from the scales, as evidenced by the disappearance of the shine in the fresh portions of kerosene. The guanine is separated from the kerosene by centrifugation and then fermented with pepsin in a hydrochloric acid environment to remove protein substances. The products of enzymatic hydrolysis are removed by washing with water. Guanine, freed from protein suspensions, is degreased with petrol, which is then removed by centrifugation. The guanine washed with water is mixed with amyl acetate and nitrolac to obtain pearl paste.

A more advanced technology for obtaining pearl paste has been developed, replacing the process of salting the scales, in which guanine is partially lost with brine, with treatment with a solution of alkaline protease – protosubtilin (G-10X or G-20X). Guanine crystals are hydrophobic, and surfactants (SAs) are used to ensure their wetting. Syntanol, DS-10, syntamide 5, etc. are used as SAs.

The technological scheme is as follows. The scales are poured with a solution heated to 40–45 ^{0}°C containing alkaline protease (0.25–0.30% of the weight of the scales) and surfactants (0.05–0.30 g/dm^{3}of the solution). The ratio of scales to solution is 1:7. The resulting mixture is stirred for 20–30 minutes, during which

the epithelial film of the scales undergoes proteolysis, guanine crystals are released and converted into a suspension. To separate the guanine, the aqueous suspension is filtered and centrifuged.

The isolated guanine crystals are poured with extraction gasoline in a ratio of 1:5, mixed, then washed four times with water in a ratio of raw guanine to water of 1:3 to remove the products of protein hydrolysis and fat residues. Each mixing lasts 20 minutes. Guanine is separated from the suspension by centrifugation and mixed with amyl acetate and nitrolac. With this method, the yield of guanine increases by 25%.

9.2.2. Disposal of waste generated during wastewater treatment at factory treatment facilities

The factory treatment facilities of fish farming enterprises include sedimentation tanks, grease traps and flotation units. Reagent treatment is used to remove colloidal and dissolved protein substances from wastewater. Each of the units collects foam, sediment or both, which must be removed, and since they contain protein and fat substances, it is desirable to utilise them.

The amount of sediment formed in sedimentation tanks during 1.5 hours of sedimentation can reach 0.01–0.025% of the volume of wastewater with a moisture content of up to 75% and a density of up to 1.05 g/cm³. Depending on the raw materials used, 1 g of organic sludge can contain up to 25% fat and up to 39% protein. The sludge formed in the flotation tank has a density of 1.12 g/cm³ at a moisture content of 80–82%. One gram of organic sediment contains up to 30% lipids, but virtually no protein. The volume of sediment is up to 0.003% of the volume of wastewater. At the same time, the density of the foam collected from the wastewater treated in the flotation unit is 0.9–0.95 g/cm³ with a moisture content of 78–80%. Per 1 g of organic matter, it contains up to 66% lipids and 35% proteins. The amount of foam mass can reach up to 0.15–0.20% of the volume of wastewater. During reagent treatment of wastewater, up to 6% of sediment is formed at a humidity of 92%. In terms of dry matter, it contains 4–12% of nitrogenous substances.

The utilisation of sludge, foam and products captured from wastewater during its treatment is of undoubted economic interest, since the chemical composition of fish waste allows it to be used as raw material for the production of valuable feed and technical products. Sediment can be dried and used as an additive in feed for farm animals and fish. Fermented sediment can be composted and used as fertiliser, while foam mass can be used to produce technical fat.

Foam mass from the grease trap and from the foam separation machine is fed through a chute into interconnected but independently operating vertical settling tanks. For better separation of the grease mass and foam product, agitators are installed in the settling tank sections. Next, the foam mass is fed through a vacuum tank to a heater, from where the mass, heated to 75–85°^{0}C, enters a centrifuge or separator. Before being fed into the centrifuge, the foam mass is heated for better fat separation.

Raw sludge from fat traps, foam separation machines, and decanters is fed by gravity or pump into a grinder and then into a collection tank, where the foam mass from the decanter is fed. After heating on the heater, the mixture goes to a centrifuge or separator for dewatering. The centrifuge and separator are installed in such a way as to ensure their parallel and sequential operation. The output of the installation is fugate (up to 50% of the initial product) in the form of a fat product that can be used for technical purposes, and a feed product that is dehydrated in a drying unit.

The sludge from the treatment plant, consisting of fish meat fibres, scales, bones, entrails and skin, should be treated with ash and lime in a ratio of 3:1:1, fermented and used as fertiliser. If the sludge contains fat, it is recommended to degrease it first. One such method is to treat the sediment with a 3% sulphuric acid solution, heat it with steam for 45 minutes, and then centrifuge it for 15 minutes at 3000 rpm. The fat yield can reach 5 – 7 %. However, the fat is viscous, dark in colour and, in terms of its main indicators, meets the requirements for grade II technical fat, with the exception of the acid number, which can be 20 – 50.

Foam mass can be treated in a similar way. To do this, it is recommended to add a 0.1% solution of hydrochloric (sulphuric) acid or a 0.65% solution of caustic soda in an amount of up to 3% of the foam mass. The mixture is heated to a temperature of 90–95°^{0}C for 40–45 minutes, and then centrifuged for 15 minutes at 3000 rpm. The foam mass is divided into 4 fractions: fat – up to 15%; protein – up to 30%; water – up to 50%; sediment – 5%.

The protein part is dried at 85°^{0}C and ground. From 1 dm³ of foam mass, up to 150 g of powder with a moisture content of 12% can be obtained. The fat yield can be about 5% of the foam mass.

For better fat extraction from the foam mass, fish processing plants recommend additional treatment with a solvent, such as chloroform or isopropyl alcohol, after treatment with acid or alkali. The solvent is added to the initial foam mass in a ratio of 1:0.5 and left to stand for 2 hours. The solvent is drained and the extraction is repeated 2 more times. The steeping time in these cases is 0.5 hours. The dense residue at the last stage is separated by centrifugation and washed with hot water to remove traces of the solvent. With an initial content of dry matter in the foam of 2.4–18% and total nitrogen of 0.5–1.3%, it is possible to obtain a product from the sediment with a protein content of 5–12%, fat content of no more than 5% and moisture content of 36–63%. After removing water by settling, up to 10–12% of fat can be extracted from the foam mass. The fat may meet the requirements of the standard for technical fat of grade II.

There is evidence of the possibility of using fat extracted from foam in the leather industry, for the preparation of drying oils and technical lubricants, and as binders in the production of asphalt-bitumen coatings. A technology has been developed for obtaining a cosmetic detergent from such fat – a double salt of triethanolamine and sodium acylamidoethylene sulfonic acid (DTN preparation), which includes fish fat ingredients that give the preparation good cosmetic properties and good cleaning ability. A special deodorisation technology has been adopted, using various fragrances to give the preparation a particular scent. The

yield of shampoo is 9 tonnes from 1 tonne of fat.

The Sea Foam shampoo composition, developed on the basis of the DTN preparation, contains fatty acid diethanolamides (DE amides) as the main additive, which largely determine the quality of the final product, giving the preparation the cosmetic properties necessary for shampoos – hair shine and the ability to style hair more easily.

From a sanitary and economic point of view, it is more promising to treat the effluents of individual technological processes at local facilities and obtain high-quality secondary raw materials. This also reduces the load on the plant's treatment facilities.

Questions for discussion and self-assessment

1. In what cases is deep wastewater treatment carried out at fish processing enterprises?
2. In which sectors of the food industry are membrane methods of liquid separation used, and for what purpose?
3. What is the principle of the ultrafiltration method of liquid separation?
4. What does the concept of concentration polarisation on ultrafiltration membranes mean, and what methods do you know to reduce it?
5. What materials are ultrafiltration membranes made of?
6. What is the basic operating principle of an ultrafiltration unit?
7. What is the principle behind sorption wastewater treatment?
8. What materials are used as sorbents in wastewater treatment?
9. What are the main properties of a sorbent?
10. What is the main criterion for evaluating the adsorption properties of a sorbent?
11. In what cases is it recommended to use sorption treatment of wastewater in adsorbers with a fluidised bed of sorbent?
12. How is sorption treatment of wastewater carried out in cylindrical single-stage adsorbers with a fluidised bed of sorbent?
13. What indicators characterise the quality of brines?
14. How can the aggregate stability of proteins in brine be regulated?
15. How do lipids and their oxidation products affect the aggregate stability of proteins contained in brine?
16. Which fraction of spoiled brine contains more microorganisms: the suspension or the filtrate?
17. Name the methods of brine regeneration.
18. What method of sorption purification of brine is used (static or dynamic), and how is it carried out?
19. What is the technology for treating brine using ultrafiltration?
20. What doses of coagulants and what coagulants are recommended for use in the reagent treatment of wastewater from the cooling of canned food directly in an autoclave?

21. What effect of wastewater treatment from canning cooling directly in the autoclave can be achieved in terms of the main indicators of impurities when treating it with reagents followed by electroflotation?
22. What is the technology for treating wastewater from canning cooling using tubular ultrafiltration membranes? What are the parameters and treatment effect?
23. What is the technological scheme for treating wastewater from fish defrosting using tubular ultrafilters? What are the parameters and treatment effect?
24. What is the scheme of the treatment plant and water recycling during fish defrosting by irrigation?
25. What types of pipe and heat exchanger fouling are you familiar with?
26. What causes corrosion of pipes and heat exchangers?
27. Why does electrochemical corrosion of metal occur?
28. What processes are accompanied by the formation of scale on the inner surface of heat exchangers?
29. What organisms develop in recirculating water cooling systems?
30. What water treatment methods are used to prevent scale formation in heat exchangers?
31. What methods of recycled water treatment are used to prevent biological fouling in pipes?
32. What is the subject of disposal at factory treatment facilities, and where can the disposed waste be used?
33. What are the main technological processes used to treat sludge and foam collected at factory treatment facilities?

CHAPTER 10. RAW MATERIAL PROCESSING AND PRODUCTION WASTE DISPOSAL

It is known that one of the effective ways to make rational use of agricultural raw materials is through their comprehensive processing and the disposal of waste generated during production.

During the processing of agricultural raw materials, in addition to the main product, by-products and production waste are generated, which are used as secondary raw materials.

Secondary raw materials are used in three areas:

- in the same food industry sectors where waste is generated, for the production of additional products;
- in other sectors of the national economy (feed, microbiological, chemical, medical product manufacturing, construction, etc.) as raw materials;
- in agricultural production – for the manufacture of feed for animals and poultry (beet pulp, grape and fruit and berry pomace, distiller's grains, feed yeast, vitamins, etc.), as fertilisers (manure, organo-mineral fertilisers).

Secondary raw materials are used in the food industry to produce baker's and feed yeast, food alcohol, butyl and methyl alcohol, oils for various purposes (food, pharmaceutical and technical), food acids and dyes, furfural, acidine, feed vitamins, feed and food phosphatides, dry feed and other products.

Comprehensive processing of raw materials and the introduction of low-waste and waste-free technologies make it possible to obtain additional products for food, feed and technical purposes from the processed raw materials. Reducing the consumption of material resources for the manufacture of products lowers their cost and leads to an increase in net income. The widespread introduction of efficient technological processes, waste-free technology for comprehensive processing of raw materials and reduction of fuel, electricity and auxiliary materials consumption is an important direction for reducing the material intensity of products.

Waste and by-products in the production of food products

The food industry encompasses the production of many food products that fully satisfy the human diet. During technological processes, a large amount of various wastes and by-products are generated. Currently, there are many technologies that are used to process large-tonnage waste. For example, pulp and molasses in the sugar industry, potato peelings in starch production, spent grains in the brewing industry, green waste from the production of canned vegetables, etc. The problem of using fruit pomace in the fruit processing process (s production) has been partially solved. The use of waste from the meat, fish, grain processing and other industries is also known. However, there is a large amount of low-tonnage waste that is prohibited from being discharged into the sewer system and therefore has to be disposed of.

One of the by-products of the meat industry is ***the blood of slaughtered animals***. The great biochemical value of blood lies in its high protein content

(about 90%), which includes a complex of amino acids, mineral salts and iron. Most of the blood is used in large enterprises for the production of food and animal feed. However, some of the blood, especially in small slaughterhouses and poultry farms, ends up in wastewater. A small amount of blood is evaporated, pressed and transported to disposal plants or fattening stations.

The rumen (a product of incomplete digestion) found in the stomachs of cattle contains up to 400 g of microorganisms. These microorganisms, which contain up to 180 g of digestible protein, break down fibre into simple sugars and synthesise all known vitamins, except vitamins A, B and E. It is therefore important to preserve these microorganisms and use them to prepare complete feed. Currently, caniga is mainly used as a fertiliser, which cannot be considered a rational solution to this problem.

The broths obtained during the cooking of meat and smoked products contain a certain amount of nutritional and flavour components, as well as particles of overcooked products. Currently, they are hardly used and end up in wastewater.

Of the by-products of the dairy industry, only ***whey*** is used, and even then only partially. Part of the whey, especially when milk supplies increase, ends up in the sewage system with the wastewater, and sometimes in surface water bodies, causing their pollution. In terms of COD, whey is 100 times higher than municipal wastewater. Whey should be used as feed or as a raw material for the production of lactose. It is best to feed it fresh. To prevent spoilage, it is processed into a feed product by concentrating it 8 – 9 times. There are known technologies for producing feed yeast and lactic acid from it. Today, a technology has been developed for the methane fermentation of whey to produce biogas, a vitaminised protein product as animal feed and other products.

*During the production of malt and beer****, grain waste, malt sprouts, malt fragments, hop waste, protein sediment and brewer's yeast*** are formed. The use of protein sludge and brewer's yeast is of great importance in the wastewater treatment process. Other waste products are mainly used as animal feed or feed additives. Hop waste is recommended for composting.

Protein waste is produced during the cooling of beer wort, which contains tannins with a bitter hop taste. This waste contains 50 – 60 % protein, but due to its 20% bitter hop resin and up to 30% tannin content, it is unsuitable for direct feeding to animals. It can be partially mixed with grain for fattening animals. Beer yeast, of which there is an excess of 0.9–1.2 litres of mash per 1 decilitre of beer, can be used to produce 0.5 kg of pressed yeast. Beer yeast is mainly used in dry form in the production of animal feed.

The waste products of the alcohol and yeast industry are ***molasses, alcohol yeast waste and de-yeasted mash***. At enterprises where these wastes are not utilised, they are discharged with wastewater.

The processing of potatoes produces ***potato pulp and juice***, which are waste products of starch production. Potato pulp is used as animal feed or for the production of compound feed. Juice is combined with wastewater. Fruit (especially apple) and vegetable pomace, which is produced after crushing and

pressing fruit and tomatoes (pips and seeds), pea processing waste (pods and tops), sediments formed during the storage of juices and yeast water after wine fermentation are the most important wastes and by-products of the fruit and vegetable canning industry. They are used as animal feed, fertilisers and for other purposes, as well as being processed to obtain pectin, alcohol, organic acids, dyes, etc. Unused solid waste is taken to a landfill for disposal, while other waste, such as tomato processing waste, is discharged into the sewer system. Unused by-products (juice sediments, tartar, water after pectin production, etc.) are also discharged into the sewer system.

This significantly increases the load on treatment facilities and leads to the loss of valuable ingredients in food raw materials.

Dried apple pomace is a raw material for the production of dry pectin. Soaking and water extraction of pomace is a source of contaminated wastewater, with BOC_5 reaching 13.5 thousand mgO_2 /dm^3. Due to its high sugar content 6 mg/dm^3, this water should be used in yeast production. It is also advisable to extract aromatic substances from fruit pomace for the production of soft drinks and confectionery.

Wine sediments formed after fermentation and maturation of wine consist mainly of yeast and are characterised by a high content of nitrogen, dry residue and a particularly high BOC. They contain, %: proteins – 28, fats – 6, mineral salts – 6, vitamins – riboflavin, thiamine, nicotinic acid and inositol, as well as ethyl alcohol – 10 – 12. The sediment formed during juice storage contains almost twice as much dry residue but significantly less alcohol. Ethyl alcohol and cognacs are produced from wine sediments, and juices are produced from juice sediments. Wine sediments can be used as raw material for the production of enanthic oil, which is used as a flavouring for cognacs and champagnes. Calcium tartrate can be obtained from the sediments of grape wine fermentation. Dry yeast from wine lees is a source of easily digestible proteins, mineral salts, fat and vitamins, so it is used as a high-quality feed additive for animals.

10.1. Processing of sugar beet and disposal of production waste

In Ukraine, sugar beet is the main raw material for sugar production. The bulk of the root crop consists of water (75%) and dry matter (25%). The latter contains up to 17% sugar and 8% non-sugar substances (non-sugars). Non-sugars are pulp (up to 5%) and various juice substances (up to 3%), which include nitrogenous organic (0.9–1.1%) and mineral (0.5–0.6%) substances. The sugar content of sugar beet is 12–25% (on average 16–18%).

The sugar content of beets is determined by the variety, soil and climatic conditions of cultivation, agrotechnical measures, etc. The water content of beets is up to 75%, which determines their low transportability and makes it impractical to transport them over long distances. Sugar beet is characterised by its multi-component composition, labour-intensive cultivation, and high feed value of the main processing waste. In addition to sugar, the dry matter of beet contains proteins, pectins, betaine, amides, organic acids, and other substances, which

create favourable conditions for the comprehensive processing of sugar beet.

Reducing the specific consumption of raw materials in sugar production is an important factor in increasing production efficiency, since raw materials account for about 80% of the cost of producing granulated sugar from sugar beet. Raw material savings depend to a large extent on the sugar content of the beet. Sugar content is determined by improvements in breeding and seed production, seed zoning, and advances in agricultural technology aimed at increasing yields. The organisation of agro-industrial sugar beet complexes, which bring together sugar factories and beet-growing farms, also contributes to increased production efficiency.

An important reserve for increasing the efficiency of raw material use is rational storage conditions. At the same time, mechanised beet harvesting, transportation, cleaning and storage increase damage to root crops, which leads to the development of undesirable biochemical and microbiological processes in the piles. Therefore, there is a problem of finding ways to reduce beet weight loss and sugar content during storage, transportation and processing.

When placing beets in storage, wilted specimens are selected so as not to mix them with healthy ones. Active ventilation of beets and treatment of root crops with a solution of sodium salt of maleic hydrazide (GMK-Na) help reduce raw material losses by 0.3% or more compared to the norm.

Storing beets in complex mechanised warehouses equipped with an active ventilation system and hydraulic feeding of beets for processing also has a positive effect on fruit preservation. The use of preparations that inhibit the processes of rotting and sprouting of beets (for example, etrel – a physiologically active substance, an aqueous solution of carbonic amide, slaked lime, phenol-based preparations, FKh-1, FM-1, etc.) also helps to reduce losses during storage. Thus, the use of GMK-Na and pyrocatechin preparations helps to reduce the weight of sprouted root crops by up to 40%, and FM-1, FH-1, carbon ammoniate and etrel preparations by up to 50%. Pyrocatechin, etrel, carbon ammoniate and FH-1 preparations have the greatest effect in inhibiting decay and sprouting processes.

Maintaining optimal production duration helps to reduce raw material costs. Soil and climatic conditions affect the technological quality of raw materials, in particular sugar content, which ultimately determines the appropriate duration of production. Technical factors also play a significant role: the method of beet storage, the degree of completeness of the technological production system, etc. The availability of beet processing capacity has a significant impact on reducing the duration of production. Concrete platforms and mechanised warehouses with active ventilation are being built at beet reception points for beet storage. Concentration of production in the sugar industry is an important reserve for increasing its efficiency.

The production capacity of sugar beet factories is increased by enlarging the size and capacity of equipment. This helps to reduce the metal content of equipment, its specific cost, and increase the use of production areas and improve the use of fixed assets. At the same time, as the capacity of the sugar factory

increases, so does the radius of its raw material base and the distance of raw material delivery. It is also advisable to use a two-stage method of sugar production, in which raw sugar is produced at low-capacity sugar factories, and granulated sugar of the required quality is produced at powerful specialised factories. One of the effective ways to increase production capacity is to reconstruct and expand existing sugar factories.

Technology is being improved through the introduction of new techniques, the development of high-capacity equipment, automated process control systems, recycled water supply systems, and continuous diffusion apparatus. Sugar losses are reduced by drying sugar beet pulp before diffusion leaching, improving the quality of beet pulp and leaching water, and maintaining a rational temperature regime. To reduce unaccounted sugar losses (microbial decomposition of sucrose during diffusion), the beets are treated with a solution of chlorinated lime, the conveyor washing water is limed, separate the conveyor water from the beets more thoroughly, use ammonia- e condensate instead of barometric water, and add formalin to the diffusion. These measures are of great importance when using recycled water to reduce fresh water consumption.

An important source of improvement in the use of raw materials in the sugar industry is the reduction of sugar losses with molasses (such losses account for about 20% of the sugar content in beets). The main reason for the increase in sugar in molasses is the deterioration in the technological quality of beets (significant contamination, high content of green mass and root crops with severe mechanical damage, increased content of harmful nitrogenous substances, reduced content of alkali metals and phosphates).

The reduction of sugar losses with molasses can be achieved by purifying the juice using the following technological methods: maximum possible removal of pulp, preliminary defecation, addition of calcium carbonate for the first saturation and lime for the second saturation.

Purification of defecated juice makes it possible to improve the quality of purified products by 0.5–2% and, accordingly, reduce the sugar content in molasses by 0.1–0.6% of the beet mass. Increasing the adsorption capacity of calcium carbonate during the first saturation has a positive effect on the removal of non-sugars from the juice.

When processing beets with low technological indicators, it is effective to add lime during the second saturation. As a result, the caloric content of the juice decreases, the sugar content in molasses and ash in white sugar decreases, as does the amount of soluble calcium salts due to additional adsorption on the surface of the formed calcium carbonate of amino acids, melanoids, and products of alkaline decomposition of inverted sugar.

To reduce the sugar content in molasses, it is necessary to increase the heat resistance of the products in order to prevent the decomposition of sucrose. To do this, it is necessary to increase the duration of the main defecation, apply combined cold-hot defecation, carry out defecation before the second saturation, and maintain the optimal pH of the sulphited juice and syrup.

During the production of sugar from beets, in addition to the main product –

granulated sugar – by-products and waste are formed: pulp, molasses, filtration sediment, etc., the rational use of which is shown in Tab. 10.1. *(infographic 1).*

Table 10.1. By-products and waste in the production of sugar from beet

<table>
<tr><td colspan="3">By-products and waste of production</td></tr>
<tr><td>Fresh beet pulp:</td><td>Molasses:</td><td>Filtration sludge (defecate):</td></tr>
<tr><td>Sour</td><td>Ethyl alcohol</td><td>For fertilizers</td></tr>
<tr><td>Dried</td><td>Baker's yeast</td><td rowspan="8">For construction needs</td></tr>
<tr><td rowspan="7">Briquetted or granulated with chemical additives</td><td>Feed yeast</td></tr>
<tr><td>Food acids</td></tr>
<tr><td>Acidin</td></tr>
<tr><td>Glutamic acid</td></tr>
<tr><td>Vitamin B_{12}</td></tr>
<tr><td>For animal feed</td></tr>
<tr><td>Solvents</td></tr>
</table>

Beet pulp is formed during the extraction of juice from beets by diffusion. The yield of pulp in diffusion batteries is 90% of the weight of beets and up to 80% in continuous diffusion apparatus. The pulp consists of 5 – 6% dry matter, with the rest being water. The dry matter contains proteins, sugar, pectin, fibre, etc. Therefore, pulp is a good, easily digestible feed, which occupies an intermediate place between hay and oats.

Fresh pulp is considered to be unpressed pulp after it has left the diffusion apparatus and has been stored for no more than three days. The dry matter of fresh pomace contains, %: crude protein – 10, including protein – 8.6; fibre – 22.9; nitrogen-free extractive substances – 62.9; minerals – 4.2. Since fresh pulp contains a lot of water, it is not practical to transport it over long distances. It is used for feeding animals, placed in a pulp pit for long-term storage or drying.

Sour pulp is pulp that has been placed in a pulp pit in a thick layer and fermented by lactic acid bacteria. This reduces its mass by 35–40%, as some of the water is removed from the pulp. The dry matter of sour pulp contains, %: crude protein – 14, including protein – 12.3; fats – 2.6; fibre 32.5; nitrogen-free extractive substances – 43; minerals – 7.

Under unfavourable conditions, microorganisms in the pomace can produce not only lactic acid but also butyric and acetic acids, which give the pomace an unpleasant odour. During storage, the loss of feed quality of pomace can reach 60%. The acidic pomace water that is formed in this process is harmful wastewater that must be disinfected and further processed.

Dry pomace is a product dried to a moisture content of 10–12%. Its yield is up to 8% of the raw pulp mass. Most of the water is removed in pulp presses. After settling and sediment removal, the pressed pulp water is sterilised in a mixture with pre-treated hot condensation water and returned to the diffusion process for sugar extraction from beet pulp. Dry matter of dried pulp, %: crude

protein – 10.2, including protein – 8.9; fat – 0.23; fibre – 21.7; nitrogen-free extractive substances – 65.8; minerals – 4.2.

Advantages of dry pulp: it retains almost all the nutrients contained in fresh pulp; the total nutritional value of dry pulp is 10–12 times higher than that of fresh pulp; the digestibility of protein and extractive substances is 75–77%. Dry pomace is transportable, and dry substances are practically not lost during storage.

The disadvantage of dry pomace is its low protein content (10.2%), which in practice is compensated for by the organisation of the production of enriched types of dried pomace. Fuel consumption for drying is quite high, which increases the cost of one feed unit by 2.5–3 times. Therefore, it is advisable to dry pulp intended for long-term storage or transportation over long distances.

Based on the research conducted, the Scientific Research Institute of the Sugar Industry recommends the following technological schemes for the preservation and enrichment of fresh, pressed and dry pomace: biological preservation of raw pomace in pomace storage facilities; chemical preservation and enrichment of raw pressed pulp; production of molasses, amide, distiller's grains and amide-mineral dry pulp.

In the case of biological preservation of pomace with lactic acid starter culture, the loss of dry matter in pomace during storage is reduced and its organoleptic properties are improved. The use of chemical preservation and enrichment of raw pressed pulp reduces dry matter losses during storage by 3-4 times and doubles the protein value of the pulp compared to the storage of conventional pressed pulp.

Dried pomace has a very low bulk density – 250 kg/m^3. Large-capacity warehouses are required for its storage. Therefore, it is advisable to store dried pomace with additives in the form of briquettes with a bulk density of about 750 kg/m^3. Since briquettes require preliminary grinding, it is more expedient to produce dried pulp in the form of granules, for which pulp drying shops are equipped with granulators. Dried beet pulp is also used in some countries (Sweden, Germany) for the production of food pectin.

Molasses is an intercrystalline mother liquor that is separated by centrifuging the last product of sugar production. With a yield of 3.5–5% of the beet mass, it contains about 50% of dissolved sugar, which is 10–15% of the total sugar contained in the processed beet.

Molasses is used as a feed additive, in the production of compound feed and for enriching roughage. It ferments effectively into alcohol. Therefore, most of it is sent to molasses-alcohol plants. At these same plants, molasses is also used to grow feed yeast. Yeast factories use it to produce baker's yeast. Molasses is also a raw material for the production of citric, lactic and other organic acids. Sugar can also be extracted from molasses.

In terms of chemical composition, molasses is a concentrated solution of sucrose and non-sugars, from which further extraction of sugar using the usual method of sugar production from beet is impossible. The use of special methods for precipitating sucrose from molasses with alkali metal oxides (calcium, barium, strontium separation) makes it possible to extract sugar from molasses quite

completely (up to 75–90%).

The chemical composition of molasses, % by weight: dry matter – 82; including sucrose – 48.4; non-sugars – 33.6; water – 18. Molasses non-sugars contain organic and inorganic substances. Organic non-sugars consist of nitrogen-free and nitrogen-containing substances.

Nitrogenous substances include betaine, pyrrolidone carboxylic acid, glutamic acid, aspartic acid, leucine, isoleucine, glycine, alanine, and valine. Non-nitrogenous sugars are found in carbohydrates (inverted sugar, raffinose) and organic acids (lactic, formic, acetic, butyric, citric). Molasses contains small amounts of iron, cobalt, lead, boron, silicon, silver, iodine, manganese, and molybdenum.

Desugaring molasses is one of the oldest ways of using it, allowing sugar factories to obtain additional sugar. However, this method is not always economical and depends on a number of factors: the amount of molasses obtained, the possibility of its use for other purposes, the need to extract additional sugar, etc.

In addition to separation for additional sugar extraction from molasses, a method for demineralisation of sugar beet products using ion exchange resins has been proposed. This makes it possible to extract an additional 0.7–1% of crystalline sugar from the mass of processed beets and to remove certain non-sugars (e.g., glutamic acid).

The sugar yield from molasses can also be increased by using surfactants during the cooking of the mash, continuous boiling of the mash, automation of the boiling process, special preparation of water for diffusion, purification of green molasses, and the use of aseptic preservation of syrup, etc.

Molasses is effective for use in feed production because, in addition to sugar, it contains amino acids, mineral salts, trace elements, and vitamins.

Molasses should be used with pomace, bran, silage, etc. Due to its high nutritional qualities, good digestibility and content of biologically active substances, the effectiveness of compound feed with molasses is significantly increased and in terms of feed value, it can replace 75% of corn.

Molasses is also used in the manufacture of feed to stabilise carotene in grass meal, in the production of grass meal pellets and compound feed. Molasses used for the production of grass meal should contain no more than 0.6% reducing sugars and 75-79% dry matter. The viscosity should be 4 – 5 Pa • s (at a temperature of $40^{\circ 0}$C).

Molasses is a raw material for the production of ethyl alcohol, glycerine, butanol, acetone, lactic, propionic and other acids by anaerobic fermentation; food and feed yeast, acetic, itaconic, citric and oxalic acids by aerobic fermentation; glutamic acid, sodium glutamate, sorbitol, furfural and mannitol in the case of chemical processing.

Molasses is used in explosives during blasting operations, to strengthen paints for ceiling painting, to manufacture moulding materials in foundries, and to dry wood. It is added in the manufacture of adhesive compositions, plastics, enzymes and a number of chemical compounds used in the pharmaceutical,

chemical and other industries.

The filtration residue is a product of the interaction of non-sugars in the diffusion juice with lime and carbon dioxide during the purification process. Chemical composition of filtration juice, % to dry matter: sugar – 2.0; pectin substances – 1.7; nitrogen-free organic substances – 9.5; nitrogenous organic substances – 5.9; calcium carbonate – 74.2; calcium in the form of salts of various acids – 2.8; other minerals (including phosphates) – 9.9. Filter sediment is formed in sugar factories during the preliminary and main defecation of I and II saturation, sulphitation and intermediate filtration of juice.

Filter sediment (defect) is a mineral (limestone) fertiliser, especially for liming acidic soils. It neutralises excess soil acidity, improves the water resistance and looseness of clay soils and the absorption of fertilisers, especially nitrogen and phosphorus. Pre-saturation sediment enriched with organo-mineral substances is also used as an additive to animal and poultry feed.

In dry form, ground pre-saturation sediment has the following chemical composition, % by dry matter weight: calcium carbonate (calculated as CaO) – 32.0; phosphates (calculated as $P_2 O_5$) – 3.0; magnesium carbonate (calculated as MgO) – 2.6; organic substances – 33.0; total nitrogen – 1.0; crude protein – 6.2; sugar – 1.0; microelements: silicon – 0.1; aluminium – 0.1; iron – 0.1; manganese – 0.07; copper – 0.003; zinc – 0.005; cobalt – 0.005; others – 0.005.

In order to reuse filtration sludge in the sugar industry, it has been proposed to regenerate lime and carbon dioxide (IV) from it. For this purpose, it is calcined in rotary kilns of the cement type or in shelf-type and spray kilns. However, a significant obstacle to the use of this method of filtration sediment regeneration is its powdery state and non-sugar content. The latter accumulates in the resulting lime, deteriorating its quality, and requires periodic removal. Abroad, filtration sediment is mainly used as a fertiliser for acidic soils. Defects are often mixed with sludge from conveyor washing water settling tanks and used as fertiliser. Dried filtration sludge with a moisture content of 30–35% stores well. When packed in bags, its moisture content should not exceed 8–10%.

Sugar beet production waste includes beet pulp and beet tails, which account for up to 3% of the weight of processed beets in washing departments. Their sugar content is 30–40% lower than that of beets.

Beet tails and fragments cannot be stored for long because they rot quickly. Therefore, they are fed to animals fresh or dried together with pulp. It has also been proposed to use them for sugar processing together with the main mass of beets. To do this, they are collected, washed and sorted, after which the larger fractions are sent to the sugar production line, and the smaller ones are used on livestock farms.

Conveyor and washing water from sugar factories is discharged from sedimentation tanks into category III drains. This wastewater undergoes mechanical treatment in earth settling tanks and then goes to filtration fields or biological ponds for natural biological treatment. This results in increased fresh

water consumption and requires large areas for filtration fields.

Sugar factory wastewater contains a significant amount of organic matter and is a valuable fertiliser for growing fodder crops. Thickening and dewatering of conveyor wash water sludge in a vertical settling tank and a horizontal continuous screw centrifuge makes it possible to reduce the amount of wastewater discharged and create a closed system of recycled water supply for hydrotransport and beet washing, obtain dewatered transportable soil sludge and increase the efficiency of existing category III wastewater treatment facilities.

Recently, new methods for treating sugar production wastewater have been developed and implemented, based on anaerobic and aerobic processes for decomposing impurities. The use of an anaerobic process in the treatment scheme increases the efficiency of treatment and significantly reduces the land area required for treatment facilities.

Modern technology for treating wastewater from sugar production involves three stages: mechanical, anaerobic and aerobic.

Anaerobic treatment is characterised by minimal bio-sludge growth and the conversion of carbon-containing impurities mainly into biogas, the main component of which is methane. The anaerobic treatment method is economically viable for water with a pollution level of more than 1 g O_2/l BOC_5. The upper limit is not limited and can be 100 g O_2/l COD. Certain inconveniences of the anaerobic method lie in the need to maintain the process within a temperature range of 36–38 ^{0}C. However, this is not an obstacle for sugar factories, as they have sufficient waste heat (condensate from evaporation units and vacuum apparatus) that can be used for this purpose. The modern wastewater treatment scheme used in the Czech Republic and other countries is shown in Fig. 10.1.

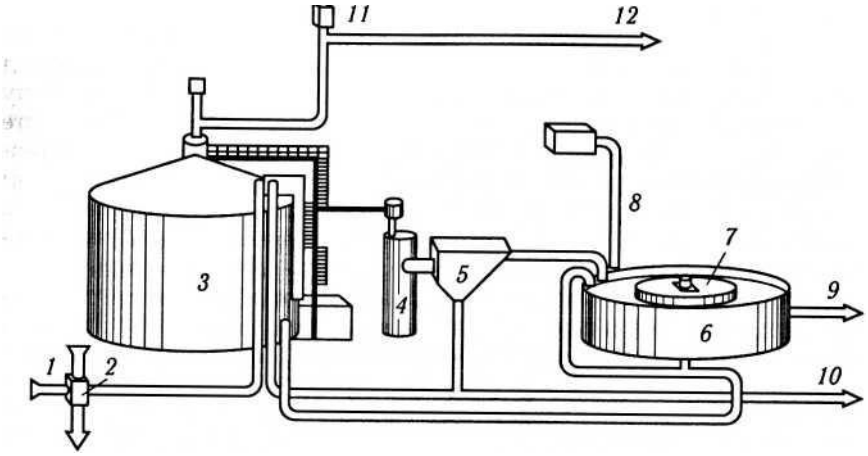


Fig. 10.1. «Anbico» biological wastewater treatment plant:
1 – wastewater for treatment; 2 – wastewater heating; 3 – reactor (fermenter); 4 – flocculator; 5 – thin-layer sedimentation tank; 6 – aerobic fermenter; 7 – clarifier; 8 – aeration system; 9 – treated water; 10 – excess sludge removal; 11 – excess gas burner; 12 – biogas for operation

The main stages of this scheme, as well as others similar to it, are mechanical cleaning and anaerobic-aerobic processes.

10.2. Raw material processing and waste disposal in the alcohol industry

Alcohol industry enterprises produce ethyl alcohol from grain, potatoes and molasses. The main types of grain crops processed into alcohol are rye, barley, wheat, corn, millet and oats.

Grain contains on average 14% water and 86% dry matter, including 52% starch. Potatoes are one of the best types of raw materials for alcohol production, containing 25% dry matter, including 18.5% starch and 75% water. The starch content determines the alcohol yield. Thus, 1 tonne of potatoes with a starch content of 13.6–14.4% yields 9.2–9.4 decilitres of alcohol.

Improvements in alcohol production technology are developing in two directions: the improvement of traditional technologies and the development and application of new technologies based on the latest scientific research achievements.

The improvement of existing technologies aims to maximise the intensity of the process while making more rational use of agricultural raw materials.

The alcohol industry is introducing continuous production processes and intensifying technological processes related to the use of enzyme preparations for saccharification of raw materials. More productive strains of microorganisms have been selected, and the technology for growing deep cultures of these microorganisms has been improved.

One of the promising areas for improving saccharification processes is the use of enzyme preparations to intensify the hydrolysis of the non-starch part of raw materials and the use of stabilised enzyme systems. Reducing the consumption of raw materials per unit of output significantly reduces raw material costs. For example, increasing the alcohol yield by only 1% saves 0.32 tonnes of grain or 1.07 tonnes of potatoes. The use of enzyme preparations contributes to this.

Recently, UkrNDIspirtbioprod has developed an energy-saving two-product technology for processing molasses into ethyl alcohol and yeast. The essence of this technology lies in a two-stage method of fermenting molasses mash, which combines the most advanced technologies of yeast cultivation and anaerobic fermentation with the repeated use of biomass. The main feature of the technology is the intensification of biomass synthesis during yeast generation and its separation after this stage, as well as the anaerobic fermentation of molasses mash of increased concentration with yeast recirculation, which enhances the alcohol-forming capacity of the latter.

The joint production of ethyl alcohol and baker's yeast enables enterprises to significantly increase their economic efficiency by:

- an increase in alcohol yield by 0.5–0.9 decilitres per 1 tonne of standard molasses starch;
- reducing the consumption of drinking water for the preparation of wort and washing of baker's yeast;
- reducing the specific heat consumption for distilling mash by 25–30%;
- a 20% reduction in the volume of post-alcohol molasses stillage.

The development and implementation of new high-efficiency equipment also contributes to increased production efficiency: continuous action units,

vacuum cooling and saccharification of wort, etc.

Compliance with temperature conditions (active and passive ventilation, airing, artificial cooling) contributes to a reduction in raw material costs during storage. Particular attention should be paid to pest control and other raw material storage measures.

In addition to the main product, alcohol, the production of alcohol also generates by-products and waste: distiller's grains, saccharomyces yeast, fusel oil, ether-aldehyde fraction, carbon dioxide, etc. (Tab. 10.2., *infographic 2*).

Table 10.2. By-products and waste in alcohol production

<table>
<tr><td rowspan="10">By-products and waste of production</td><td rowspan="2">Grain-potato distillery spent wash (vinasse)</td><td colspan="3">For animal feed</td></tr>
<tr><td colspan="3">Feed yeast</td></tr>
<tr><td rowspan="2">Ester-aldehyde fraction</td><td colspan="3">Alcohol</td></tr>
<tr><td colspan="3">For use in specialized production</td></tr>
<tr><td rowspan="2">Fusel oil</td><td colspan="3">In perfumery production</td></tr>
<tr><td colspan="3">In milk industry</td></tr>
<tr><td>Carbon dioxide</td><td colspan="3">For production of liquid CO_2 and dry ice</td></tr>
<tr><td rowspan="4">Molasses distillery spent wash (vinasse)</td><td rowspan="4">Yeast</td><td>Baker's</td><td></td></tr>
<tr><td>Feed</td><td></td></tr>
<tr><td rowspan="2">Secondary spent wash (vinasse)</td><td>Vitamin B_{12}</td></tr>
<tr><td>Granulated organo-mineral fertilizer</td></tr>
</table>

Distiller's grains are a waste product of alcohol production. They are formed during the distillation of mash. Depending on the raw material, there are grain, potato, molasses and secondary distiller's grains, which are formed during the cultivation of feed yeast.

The dry matter content depends on the mash assortment and ranges from 3 to 8%. They contain nitrogenous substances (proteins, amino acids, etc.) and non-nitrogenous substances – carbohydrates (dextrins, sugars, starch, pectin substances and other carbohydrates, except for fibre and hemicellulose), fats and minerals (Table 10.3).

Table 10.3. Chemical composition of distiller's grains, %

Type of distiller's grains	Dry matter	Protein	Carbohydrates	Fats	Fibre	Minerals
Cereals	6.7 – 8	26.8 – 27.5	40.0 – 41.8	5.9 – 7.5	–	–
Potato	3.2 – 4.1	18.7 – 19.5	56.2 – 58.5	3	–	–
Secondary	5.4 – 5.8	21.5 – 22.9	52.0 – 53.2	–	17.9 – 19.3	6.0 – 7.2

Distiller's grains also contain B vitamins and are considered a valuable product with a feed value of 25–30% of the feed value of the raw material. Distiller's grains are a protein feed and a good medium for growing

microorganisms that produce proteins and vitamins. When growing feed yeast on grain-potato distiller's grains, secondary distiller's grains are formed, which contain 1.5 times more B vitamins than natural distiller's grains. Secondary distiller's grains are used to feed cattle.

The yield of grain-potato distiller's grains depends on the type of raw material, processing technology and alcohol content in the mash. With an alcohol content in the mash of 8.0–8.2%, 13.5–13.8 decilitres of distiller's grains are obtained per 1 decilitre of alcohol.

The quality of distiller's grains is assessed by the content of digestible protein. The content of the latter is 2–3 times higher than in the raw material. The dry matter of grain distiller's grains contains vitamins, mcg/g: riboflavin – 3–4; thiamine – 1.5 – 4.5; nicotinic acid – 18–75; pantothenic acid – 4–8. Currently, the bulk of grain-potato distiller's grains is fed to farm animals.

The use of fresh distiller's grains is somewhat difficult, since storing them in the summer for more than a day leads to protein decomposition and rotting. Therefore, the best way to utilise grain-potato distiller's grains is to use them for growing microorganisms, feed yeast and obtaining other protein products.

Dry feed yeast is produced from distiller's grains. Yeast cells synthesise protein, vitamins and other biologically active substances. The protein absorption coefficient of feed yeast is 0.85–0.90 compared to 0.52 for distiller's grains. The biological value of feed yeast protein significantly exceeds that of plant-based protein and is close in quality to the protein of the best feed product – fish meal.

Feed yeast contains phosphorus, calcium, amino acids, enzymes, hormones, vitamins, mcg/g of dry yeast: thiamine – 25–30, riboflavin – 40–60; pantothenic acid – 130–160, nicotinic acid – 500–600, etc.

The protein content in dry yeast is: during grain processing – 45%, potatoes – 13%. About 6.1 thousand decilitres of grain-potato distiller's grains are spent on growing 1 tonne of feed yeast. The yield of feed yeast from natural distiller's grains is 8.5–9 tonnes per 1,000 decilitres of alcohol during grain distiller's grains processing and 5.5–6 tonnes per 1,000 decilitres of alcohol during potato distiller's grains processing.

Growing feed yeast on natural distiller's grains ensures waste-free production, eliminating the need for large land areas for filtration fields and significantly improving the environmental situation at industrial sites. At the same time, it provides agriculture with additional feed rich in digestible forms of protein, vitamins and protein.

The processing of molasses distiller's grains into ethyl alcohol creates conditions for its comprehensive use and disposal of production waste.

During the processing of molasses into alcohol, post-alcohol distiller's grains, saccharomyces yeast and carbon dioxide are obtained as waste products.

Carbon dioxide is used to produce liquid CO_2 and dry ice. Saccharomyces yeast is used to produce baker's yeast and protein products. Post-alcohol stillage is mainly used to grow feed yeast, the waste product of which is post-alcohol molasses stillage.

The composition of molasses post-alcohol distiller's grains depends on the

quality of the initial molasses and the technology used to process it. The dry matter content is 6–10%. The value of post-alcohol distiller's grains is determined by the content of organic nitrogen compounds. Thus, per 100 g of total nitrogen, it contains 88–92 g of betaine and amino acids and 4–5 g of proteins and peptides. Currently, almost all alcohol plants grow feed yeast during the production of acidine and glutamic acid. Evaporated post-alcohol distiller's grains can be used as a feed supplement for cattle.

The Ukrainian Research Institute of Alcohol and Bio-Products has developed a technology for the utilisation of grain distiller's grains to obtain dry protein feed, the feed value of which is 25–30% higher than that of grain. According to this technology, grain distiller's grains are divided into a part concentrated to 30% dry matter and a fugate. As a result of further heat treatment, dry grain distiller's grains are obtained as a commercial product. The latter is used to feed cattle, pigs, sheep, poultry, fish, etc. It makes it possible to replace up to 50% of soybean meal protein and similar products in feed rations.

The advantages of the proposed technology include:

- obtaining dry protein feed of high nutritional value;
- the possibility of using both concentrated native distiller's grains and dry grain distiller's grains for animal feed;
- replacing up to 95% of the components of compound feed for poultry with dry distiller's grains, while reducing its cost;
- water savings through the use of part of the fugate during alcohol production.

The technology for utilising post-alcohol distiller's grains from molasses distilleries involves the production of concentrated liquid organo-mineral fertilisers for long-term storage or desalinated distiller's grains for feed and mineral fertilisers with a high potassium content (up to 30%). This technology involves evaporating native distiller's grains to a concentration of 70–75% dry matter (organic-mineral fertilisers) and, if necessary, partially desalinating it (feed distiller's grains and mineral potassium fertilisers).

Evaporated molasses distiller's grains and desalination waste are used as highly effective organo-mineral fertilisers in crop production.

Desalinated distiller's grains are used as a feed additive for fattening cattle, producing feed mixtures, granulated compound feed, silage, and increasing the feed value of pomace.

Recently, alcohol plants that process grain raw materials have had difficulties using post-alcohol distiller's grains for feed. Therefore, dry distiller's grains are produced from it as protein feed for animals.

Post-alcohol grain distiller's grains are separated into solid and liquid fractions in centrifuges, vacuum filters or decanters. The liquid fraction is partially returned for the production of mash, and the rest is processed according to two technological schemes. In the first scheme, it is concentrated in an evaporation unit and, after mixing with the solid fraction, dried in a drum dryer. As a result of the evaporation of the liquid fraction of the distiller's grains, secondary vapour condensates are formed, which have a COD of 1200–1400 mg O_2/dm^3. According

to the second scheme, the liquid fraction enters anaerobic bioreactors, where it undergoes anaerobic fermentation with the formation of biogas. During anaerobic pre-treatment, the pollution of the liquid part of the distiller's grains is reduced by 90% in terms of COD, and biogas with a methane content of 70% is formed in an amount of 1400–1600 m³ per 1000 dal of alcohol.

Enterprises that sell post-alcohol distiller's grains discharge mainly water from washing equipment and luter water to treatment facilities.

At alcohol plants that have baker's yeast workshops, saccharomyces yeast is extracted from alcohol mash and used as baker's yeast. In this case, unfermented distiller's grains are used to grow feed yeast. In the absence of baker's yeast workshops, the distiller's grains obtained during distillation contain dead saccharomyces yeast and are used in this form for the cultivation of feed yeast.

During the production of dry feed yeast grown on post-alcohol molasses stillage, post-yeast stillage is formed. Chemical composition of stillage, % by dry matter: total nitrogen – 3.2 – 5.4; sulphates – 30.0–50.0; chlorides – 26.0–43.0; free amino acids – 0.85–1.5; glutamic acid in hydrolysed distiller's grains – 0.5–3.0; reduced substances – 1.0 – 6.0; glycerine – 2.0 – 5.0; betaine – 8.0 – 25.0; fat-like substances – 0.7 – 6.0.

Post-yeast distiller's grains are produced in an amount of 120% of post-alcohol distiller's grains, or about 14 decilitres per 1 decilitre of ethyl alcohol. Currently, it is used for the production of granular organo-mineral fertilisers (OMF); in hydrolytic yeast production; for the production of vitamins; for fertilising and irrigating land; and in the cement industry.

Carbon dioxide. Until recently, liquid carbon dioxide was used only for the production of soft drinks, mineral waters, sparkling wines, and cider. Recently, its use has grown dramatically for technical needs: in mechanical engineering, oil production, energy, and agriculture.

During the fermentation of starch and sugar-containing raw materials into ethyl alcohol, 95.5% of carbon dioxide is formed relative to the mass of alcohol.

For every 1,000 decilitres of raw alcohol, approximately 5 tonnes of liquid carbon dioxide can be obtained. Its yield depends on the type of raw material being processed and amounts to 88.1 kg per 1 tonne of potatoes and 244.7 kg per 1 tonne of grain during fermentation.

For more complete utilisation of the carbon dioxide released during fermentation, it is advisable to install large containers for the collection and storage of CO_2 at alcohol plants, for example, isothermal tanks NZH-46 with a capacity of 46 tonnes of carbon dioxide.

Liquid carbon dioxide is also used to produce dry ice. The latter is used as a refrigerant, as well as in the chemical industry and medicine. The yield of solid CO_2 (dry ice) from 1 tonne of liquid carbon dioxide is 500 kg.

Fusel oil is formed as a by-product of alcoholic fermentation, the main component of which is higher alcohols. Fusel oil consists of polyhydric alcohols – allyl, isoamyl, butyl, isobutyl, propyl and isopropyl – as well as esters, ethyl alcohol and water.

Fusel oil is separated from raw spirit by repeated distillation (rectification). The composition of fusel oil and its yield depend on the type of raw material, production technology and the physiological state of the yeast. The greatest amount of fusel oil is formed during the fermentation of grain raw materials, and its yield can vary between 0.2 and 0.4%.

Higher alcohols are obtained during the rectification process. Amyl alcohol is particularly valuable and is widely used in agriculture and the dairy industry to determine the fat content of milk and dairy products. Chemical plants use amyl alcohol to produce isoamyl and α-amyl optically active alcohols, which are used as laboratory reagents. Technical mixtures of amyl and butyl alcohols are used as solvents. Amyl alcohol is used to produce fragrances and to synthesise fruit essences. Amyl acetate is used in medicine for the treatment of asthma. Derivatives of propanol, which is produced from fusel oil, are used to treat nervous disorders.

The *ether-aldehyde fraction (EAF)* contained in raw alcohol is a by-product of the main alcohol production. The strength of EAF is 94–95%; depending on the type of raw material and production technology, it contains ethyl alcohol, ethers, aldehydes and water. Depending on this, the yield of EAF is 1.5–4.5% of the amount of alcohol being rectified. The main component of EAF is ethyl alcohol (more than 95%), and the main impurity is methyl alcohol. EAF is used to obtain rectified food alcohol, which is also used in the paint and varnish industry for the production of denatured alcohol.

Wastewater. Alcohol plants in Ukraine that process molasses discharge approximately 3–4.5 million m³ of concentrated wastewater into storage tanks each year, or 200–300 thousand tonnes of pollutants according to BOC. The storage tanks occupy more than 1,500 hectares of agricultural land. This leads to the pollution of surface water bodies and even groundwater, as well as atmospheric air, with unpleasant-smelling gases (methane, mercaptan, hydrogen sulphide, etc.), which are formed as a result of the destruction of organic substances in distiller's grains by microorganisms.

The amount of wastewater and its qualitative composition are determined by the type of raw materials, production technology, enterprise capacity, water supply source and wastewater disposal conditions. Depending on these factors, water consumption and wastewater quality vary widely, as shown, for example, in Table 10.4, which presents the calculated sanitary and chemical indicators of the composition of wastewater from alcohol plants depending on the method of distiller's grains utilisation.

A technology for obtaining biogas from the wastewater of alcohol plants has been developed. The technology is based on the use of highly efficient anaerobic bioreactors with specially selected anaerobic granulated biomass of microorganisms adapted to the wastewater of alcohol molasses plants. This increases the number of destructive microorganisms per unit volume of the bioreactor by tens of times, which makes it possible to significantly reduce their volume.

Using this technology, a plant with a capacity of 6,000 decilitres of alcohol per day produces approximately 5.5 million m³ of biogas per year, which is equivalent to 4 million m³ of natural gas. The use of biogas in the factory boiler room allows for significant fuel savings, while anaerobic treatment reduces wastewater pollution by 80%.

Table 10.4. Sanitary and chemical indicators of the composition of wastewater from grain processing alcohol plants

Indicator	Wastewater without distiller's grains	Wastewater with evaporation station	Wastewater together with the liquid fraction of distiller's grains after anaerobic treatment
pH	6.5 – 7	6	7
Dry residue, mg/dm³	1203	1470	2970
Calcined residue, mg/dm³	540	265	1850
COD, mg O_2/dm³	73	1353	1230
BOC_{total}, mg O_2/dm³	620	1044	1050
Ammonium nitrogen, mg/dm³	65	145	413
Chlorides, mg/dm³	150	40	296
Sulphates, mg/dm³	80	63	218

For more complete wastewater treatment after anaerobic treatment, it is further treated in aerotanks under aerobic conditions using microorganisms immobilised on a fixed fibrous carrier. Compared to the use of free-floating activated sludge, this treatment has the following advantages:

- low sensitivity to fluctuations in wastewater flow and concentration;
- increased treatment efficiency;
- possibility of prolonged shutdowns;
- accelerated transition to the regulated treatment mode;
- 30% reduction in specific air consumption;
- 5-10 times reduction in biomass growth of immobilised microorganisms.

The bacterial biomass that accumulates on the immovable carrier is partially consumed by protozoa and maintained at the required level.

During the aerobic treatment process, excess sludge is formed, which is a high-protein product and can be an additional source of microbial protein feed. Water purified in aerotanks to BOC 12–15 mg O_2/dm³ is further purified for 15–30 days in bioreactors to BOC 4–6 mg O_2/dm³. After disinfection with active chlorine and holding for 30 minutes in a contact tank, the purified water is discharged into natural water bodies.

10.3. Processing of raw materials and waste disposal in the oil and fat industry

The raw materials in the oil and fat industry are the seeds and fruits of plants belonging to the oilseed group: sunflower, peanut, soybean, cotton, hemp, as well as wheat, corn, rice, etc. In Ukraine, sunflower, soybean, rapeseed and corn prevail.

Depending on the oil content, sunflower seeds are classified as high-oil (43% and above), medium-oil (37 to 43%) and low-oil (less than 37%) varieties. Recently, scientists have created and regionalised various varieties with an oil content of up to 50% and a yield of over 30 centners per hectare. To produce 1 tonne of oil, about 5 tonnes of sunflower seeds need to be processed. Due to its good taste, sunflower oil is used directly in food, as well as for the production of margarine, canned food, bread and confectionery products. It is also used in soap, paint and other industries.

Recently, for a number of reasons, oilseed processing plants have seen an increase in oil losses from meal and husks during the processing of sunflower seeds. One of the reasons for oil sorption by husks is damage to the seeds during harvesting and then at all stages of kernel extraction, as well as improper storage, cleaning and drying of raw materials. Therefore, special attention should be paid to the operation of screw conveyors and elevators and the proper storage of raw materials.

In oil and fat production, in addition to the main product – vegetable oil, by-products and waste are formed: sunflower husks, meal, meal, etc. (Tab. 10.5., *infographic 3*).

Table 10.5. By-products and waste from oil and fat production

By-products and Waste of Oil Production	Press Cake	Solvent-Extracted Oil
	Oilseed Meal	For Feed Production
	Sunflower Husks	Hydrolytic Alcohol Feed Yeast
	Gossypol	Used in Petrochemical Production
	Soapstock	Used for Fatty Acid Distillation and Soap Manufacturing
	Phosphatide Concentrates	Used in the Production of Margarine, Bakery and Confectionery Products
	Spent Bleaching Earths	Used in Feed Production

During extraction, solvent losses (benzine) increase significantly, which is explained by the processing of defective raw materials, the use of worn-out equipment, and violations of technological discipline. Smaller losses are achieved when processing oil raw materials on belt extraction units.

Sunflower husks. The yield of sunflower husks depends on the sunflower variety and production technology and can exceed 40% of the seed weight. For ease of storage and transportation, it is briquetted, which increases the bulk weight by 5 – 6 times. Sunflower husks contain 1.4% of the carbon-rich pigment

phytomelin, 23.6–28% pentosans, 52–66% fibre, 24.8–29.6% lignin and 31–42.4% cellulose. It is a valuable raw material for the production of feed yeast, hydrolytic alcohol, furfural, acetone and other products.

To grow feed yeast rich in proteins, glycogen, phosphorus and vitamins, pentose-hexose hydrolysates of husks are used after removing furfural from them. The resulting yeast contains 42–52% total protein and 4–9% ash. To obtain 1 tonne of feed yeast, 6.7 tonnes of husks are used. The yeast yield is 149.5 kg.

Furfural, which is produced from husks, is used in the oil refining industry as a selective solvent for purifying oils. Furfural alcohol is used for anti-corrosion coating of equipment, as a selective solvent for extracting penicillin, as an indicator of fuel combustion in jet engines, etc.

Sunflower husks are used in large quantities as fuel, and also as animal feed and bedding. To increase the effectiveness of husks as a feed additive, they are enriched with calcium salts of fatty acids obtained during the purification of wash water from a refining plant or soap stock.

Sunflower meal is obtained during the pressing of oil from seeds, and meal is obtained during the extraction of oil in extractors. The nutritional value of meal and meal is determined by the content of protein and essential amino acids and depends on the production technology (processing of seeds with or without hulling). The nutritional value of meal from hulled sunflower seeds is 25% higher than that from unhulled seeds. Currently, sunflower seeds are processed with the husks removed. The average yield of meal using the pressing technology is 35.3%, and that of meal using the extraction technology is 39.2%. Sunflower meal is produced in regular and lipid-enriched forms. Hydration fusions obtained during the oil hydration process are used as fat enrichers. Lipid-enriched sunflower meal is produced in granulated and non-granulated forms.

Oil refining waste. During oil refining, fat-containing by-products and waste are formed. During the oil hydration process, depending on the technology and modes, phosphatides are formed in varying amounts. The average rate of phosphatide concentrate formation for sunflower oil is 0.8–1% (8–10 kg per 1 tonne of oil). Food phosphatide concentrates are used as biologically valuable feed additives in compound feed for animals and poultry, as well as in the production of margarine, for the manufacture of bakery and confectionery products and other purposes.

Soapstocks from the neutralisation of vegetable oils and fats are saponified free fatty acids with a low content of neutral fat and non-fat substances. The yield of soapstock depends on the type and grade of oil and the refining technology. As a result of the decomposition of soapstock from the refining of light oils, a fat mixture (fatty acids and neutral fat) is obtained, which can be used for soap production and other purposes.

Waxy substances. Oils from high-oil sunflowers obtained by pressing and extraction contain 0.05–0.4% waxes, respectively. The latter cause sunflower oil to become cloudy, spoil its appearance and reduce its grade. Waxes are removed from sunflower oil by cooling it to a temperature of -10–12 ^{0}°C, holding it at this temperature and then filtering it. Filtering wax powders (diatomaceous earth or perlite) are currently used as an additive to compound feed. The main consumer of waxes is the perfume industry. They are also used in the production of glossy paper, pencil leads, various polishing pastes, and in the soap, pharmaceutical and printing industries.

Spent bleaching clays (bentonites) used to clarify vegetable oils are enriched with fats. Their oil content depends on the nature of the clay and the type of filters and can vary between 40 and 60%. When bleaching clays are blown with inert gas or steam before unloading the filters, the fat content does not exceed 30% when using frame filter presses and 15% when using disc filters. Bleaching clays are used in the production of soap pastes. The paste usually contains 14-16% fatty acids and has a soft, plastic consistency. If there is not enough fat in the spent bleaching clay to make the paste, fat from the grease trap, soapstick, oil sludge in tanks, and fusel oil can be partially used. Bleaching clays are also used to prepare compound feed.

The wastewater of an oil and fat enterprise consists of 66% cooling water, 32% heavily polluted water, 1.5% sanitary water and 0.5% other water. Heavily polluted effluents contain up to 3650 mg/dm^3 of suspended solids and have a BOC of 5175 mg O_2/dm^3 (data provided for Vinnytsia Oil and Fat Plant JSC). The fat content ranges from 200 to 3500 mg/dm^3.

To treat highly concentrated wastewater with a COD value of over 2000 mg O_2/dm^3, it is advisable to use preliminary methane fermentation followed by aerobic post-treatment in aerotanks. Recirculation of activated sludge and the use of immobilised microflora make it possible to intensify the process of biotransformation of pollutants to MPC standards for their discharge into the city's sewerage network, as well as to obtain biogas and a protein-vitamin concentrate enriched with B vitamins.

10.4. Processing of raw materials and waste disposal in starch and syrup production

The main raw materials in the production of starch products are potatoes and corn, and partly wheat. The starch-syrup industry includes the following types of production:

- potato starch, which produces raw starch from potatoes and dry edible starch as a finished product;
- corn starch production, which produces dry starch and by-products – corn extract, dry corn feed and corn oil;
- glucose-syrup production, which produces caramel syrup from potato starch and crystalline glucose from corn starch.

Dry potato starch is mainly used in the preparation of sauces, sausages, jelly, puddings, biscuits, cakes and many other food products.

Dry corn starch is used in the textile industry, for the production of dextrins, adhesives, in the paper, match and other industries. Starch syrup is used in confectionery production for the manufacture of caramel, as well as in the production of bakery and spirits products. Glucose is used to make medicines, medical glucose and vitamins. Modified starch is used in oil and gas drilling, for the production of farm mixtures in foundry production, as well as for the production of ice cream and jelly confectionery.

Starch makes up the bulk of dry matter: 70–80% of the mass of potatoes and 68–73% of the mass of corn. The starch extraction rate depends on the quality of the raw materials, the level of technology and the organisation of production. With an average extraction rate of 81.8% and a starch content of 13.6%, the consumption of potatoes per 1 tonne of dry starch is 7.22 tonnes. However, in different years it varies from 6.5 to 8.1 tonnes.

During potato storage, significant starch losses are observed depending on the storage period (from 1.2% in August to 5% in April). Corn as a raw material has an advantage over potatoes because it contains 66–73% starch, which is four times more than potatoes. During potato storage, gas exchange and temperature must be systematically regulated. Minimal starch losses are observed at a temperature of 4 ^{0}°C.

Compared to other cereals, corn is less stable during storage. Corn kernels, which contain significant amounts of fat, soluble proteins, carbohydrates, minerals and enzymes, do not have a protective layer. Therefore, during storage, biological and biochemical processes intensify, leading to starch loss. At high humidity and low temperatures in the granary, mechanical damage to cells by ice crystals and denaturation of protoplasm proteins occur. Protein denaturation is also caused by storing grain at high humidity and temperature.

The viability of grain also depends on the action of microorganisms during storage. High humidity and temperature have a particularly negative effect on the shelf life of grain and starch yield. When processing frozen or overheated grain, starch and protein are poorly separated, the protein content in starch increases, the starch yield decreases to 2% and its quality deteriorates. During long-term storage of corn grain, the humidity should not exceed 14%.

By-products and waste products include pulp, potato cell juice, gluten, extract, oil, pomace, dry feed, etc. (Tab. 10.6., *infographic 4*).

Potato pulp contains, % by dry matter: starch – 50, fibre – 25, soluble carbohydrates – 2.5, minerals – 6.2, crude protein – 6 and other substances – 10.3. In its raw (moisture content 86–87%) and dry form, it is used for animal feed. Due to the high moisture content of raw pulp, it is difficult to transport, which leads to incomplete sales.

For fattening animals, it is advisable to use a mixture of raw pulp and cell juice. When processing 100 tonnes of potatoes into starch, the output of raw feed (a mixture of pulp and cell juice) is 90 tonnes (including 40 tonnes of pulp and 50 tonnes of cell juice). Due to the complexity of transportation, the pulp is ensiled

or dried. To improve the quality of the silage, protein sludge (coagulated protein from cell juice) is added to the pulp.

Table 10.6. By-products and production waste

By-products and waste of starch production	Potato Cell Sap	Protein Concentrate	Used for Feed Production
	Potato Pulp		Used for Feed Production
	Broken and Small Corn Kernels	Ethanol	
	Corn Germ	Vegetable Oil	
	Corn Gluten (Wet Gluten)	Used in the Production of Pharmaceuticals (Penicillin and Other Antibiotics)	Used for Feed Production
	Corn Steep Liquor (Corn Extract)		
	Corn Cobs	Ethanol Furfural Fuel	

Potato cell sap, which contains up to 6% dry matter, is rarely used. Its yield is 50% of the weight of the potatoes processed. The main components of the dry matter of cell sap are amino acids: lysine, alanine, glutamine, etc.

The mineral part consists of potassium oxide, phosphoric acid, calcium and magnesium compounds. Therefore, cell sap is mainly used for the production of protein feed and carbohydrate-protein hydrolysate. Protein feed is sold raw (moisture content up to 25%) and dry (dry matter content 87%). Raw feed spoils quickly and therefore must be sold quickly. For long-term storage, it is dried to a moisture content of 13%. From 100 tonnes of dry protein feed, it is possible to produce 159 tonnes of feed units, while from 100 tonnes of potatoes, it is possible to produce 29 tonnes of feed units.

During the production of protein feed, a carbohydrate-protein hydrolysate is obtained from the filtrate – 6.3 kg from 100 tonnes of potatoes. It contains glucose, sucrose, maltose and amino acids: cystine, lysine, methionine, glutamic acid, leucine, isoleucine, etc. Boiled carbohydrate-protein hydrolysate is used as a substitute for red rye malt for baking dark bread.

Waste and by-products from corn starch processing are used to make dry and wet corn feed. The latter is mainly sold in its raw form. By-products of corn starch production and waste from molasses and glucose production consist of extract, gluten, coarse and fine pulp, corn oil press cake, kieselguhr or perlite and coal filtration sediments from molasses and glucose production, and waste from elevators obtained during corn threshing. Mixed feed contains the main feed substances necessary for animals – proteins, fat, carbohydrates, and ash. The pulp, which consists mainly of fibre and starch, is the carbohydrate part of the feed. In addition to protein, fat and carbohydrates, diatomaceous sediment contains a large amount of ash (15–30%) and is included in the feed in an amount of 6–8%, which does not impair its quality.

Different varieties of corn contain 9–11% germ. *Corn germ* is used to produce corn oil. One tonne of corn oil is produced from 2.3 tonnes of germ. Germs with a moisture content of 57–60% and a bran content of 10–15% are dried and transported in dry form to oil and fat plants.

The *extract* formed as a result of soaking corn can be used as a feed ingredient or as a raw material for the medical industry in the production of antibiotics. When used in feed production, the extract is boiled down to 35–40% dry matter, and for sale to medical plants, to 48–50% dry matter.

The main sugars in corn extract are glucose and, to a lesser extent, maltose and xylose. The extract, boiled down to 50% dry matter, is used as one of the components of the nutrient medium for growing mould fungi in the production of biomicin, penicillin, streptomycin and other antibiotics and vitamin B_{12}. Corn extract is also used in the manufacture of feed. To do this, it is mixed with coarse and fine pulp and gluten and dried in rotary dryers.

Raw *gluten* is obtained at the stage of separation of the starch-protein suspension. The chemical composition of gluten, % on a dry basis: starch – 20–45, protein – 40–60, fat – 5–8, ash – 0.8–1.5, fibre – 2–4, soluble carbohydrates (sugars) – 0.5–2, other substances – 4–6. Gluten is used as a component of feed. However, it is more rational to use it as a raw material for the production of glutamic acid, sodium glutamate, protein paste and foaming agent.

Corn gluten contains 16–18% glutamic acid. Sodium glutamate is used as a food flavouring additive in the preservation of meat and fish products (in the preparation of soups, sauces, sausages, hams, and vegetable dishes). The addition of monosodium glutamate increases the shelf life and enhances the taste qualities inherent in fresh products.

During corn soaking, most of the albumins, gluten and globulins are transferred to the extract. However, corn protein – zein – remains undissolved and is separated as a by-product of production. Zein is used to make waterproof glue, in the production of plastics, and to form waterproof protective films during the manufacture of various pills. The yield of zein can be 15% of the mass of processed gluten.

Corn cobs are mainly used as fuel. However, they can be processed into valuable products such as lignin, glucose, arabinose, xylene, xylitol, xylitan, and furfural. Cobs are also used as animal feed. In terms of feed value, ground cobs are equivalent to hay or spring straw. To improve the protein composition, legume flour and wheat bran should be added to the cob flour.

Filter cake is formed in the production of starch syrup and crystalline glucose at the filtration stage. Diatomite and perlite are used as filter powder. Filter cake is a mixture of filter powder, activated carbon and fat-protein substances. It is added to corn feed in an amount of 8–10% of the total dry feed mass. The fat-protein content in diatomaceous filtration residue averages 2%.

The product of malt syrup production is *pomace*, which is formed during filtration of the mash on frame filter presses. Malt pomace is a well-cooked protein

feed enriched with malt vitamins. At a moisture content of 50–60%, it is fed to animals.

Hydrolysate is the end product of glucose production. It consists almost entirely of the products of glucose conversion and decomposition, salts and other impurities contained in starch hydrolysates. The qualitative composition of hydrolysate depends on the method of glucose production. Hydrolysate is used in the production of antibiotics for the preparation of culture media, in leather production for tanning leather, in the production of artificial fibres as a reducing agent, and also for the production of alcohol and mixed feed.

10.5. Processing of raw materials and disposal of waste from canning production

The raw materials for canned fruits and vegetables are vegetables, fruits and berries. Vegetables are divided into fruit and vegetable. Fruit vegetables include tomatoes, aubergines, peppers, peas, beans, broad beans, cucumbers, courgettes, squash, pumpkins, watermelons, melons, corn; vegetable vegetables include potatoes, sweet potatoes, Jerusalem artichokes, carrots, beets, parsley, parsnips, celery, horseradish, cabbage (white, cauliflower, Brussels sprouts), spinach, sorrel, various types of lettuce, onions, garlic, dill, marjoram, basil, savory, asparagus, etc. Vegetables contain 65 to 95% water, with the rest being dry matter – carbohydrates (sugars, starch, fibre, pectin) and fats.

The conditions of harvesting, delivery, acceptance and storage of raw materials have a significant impact on the output of finished products and the amount of waste.

The main requirements during harvesting are the absence of mechanical damage, especially when using machines and mechanisms. During storage, spoilage by microorganisms and deterioration in quality as a result of the action of enzymes must be prevented.

The storage period for raw materials at canning factories depends on the type and condition of the raw materials and usually ranges from several hours to two days. For long-term storage of vegetables (potatoes, onions, cabbage, etc.), trenches and embankments or special storage facilities with a constant temperature (1–3 ^{0}°C) and high humidity (more than 90%) are used.

Fruits and vegetables that require artificial ripening can be stored in an ethylene atmosphere. If it is necessary to delay ripening, they are placed in a carbon dioxide gas atmosphere (ratio of CO_2: O_2= 1 : 1). To extend the operating period of factories, fruits and vegetables are often quick-frozen and stored at low temperatures (–18°^{0}C).

To extend the production period of canning factories, vegetables and fruits are sulphited with sulphur dioxide, sulphurous or succinic acids. Sometimes they are sulphited in sugar syrup. In addition, aseptic methods of preservation in sterile conditions and packaging of products in hermetically sealed tanks and pools are widely used. Some semi-finished vegetable products (cucumbers, tomatoes, cabbage) are salted. Such preparation contributes to the creation of raw material

resources for the operation of enterprises in winter.

Raw materials are transported in containers and other receptacles. To reduce losses during short- and long-term storage in cold conditions, active ventilation is required. Before placing vegetables and fruits in storage, they are treated once with a solution of sodium or potassium carbonate.

Raw material savings in canning production are achieved through production and non-production factors.

Production factors include those related to improving technology and production organisation: production levels, comprehensive processing of raw materials and waste, and reducing specific consumption rates by reducing losses during storage and processing.

Non-production factors include improving the quality of raw materials and reducing losses during harvesting, transportation and storage.

Most raw materials are lost during preparatory operations (washing, sorting, calibration, peeling, trimming, removal of fruit stalks, seeds, and seed chambers).

Significant losses of raw materials are observed during blanching. Losses of dry matter can be reduced by using salt or sugar solutions for blanching, or by blanching with steam or in a vacuum in special apparatus.

The yield and quality of the finished product are also influenced by cooking, which is carried out in open double-walled cooking boilers at atmospheric pressure or in vacuum devices. Pre-freezing of raw materials makes it possible to eliminate the blanching process and, therefore, reduce the loss of soluble dry matter.

One of the most important technological processes in canning production is sterilisation, which largely determines the quality of canned food and its nutritional value.

Canned food is sterilised in three ways: aseptic sterilisation, sterilisation in syrup, and sterilisation of packaged products in a sterilisation apparatus.

The most common method is sterilisation of the product in containers in autoclaves. However, this method is characterised by high heat energy consumption and is labour-intensive. The process can be intensified by performing high-temperature rotary sterilisation in an air stream and using continuous sterilisers. This results in reduced steam and water consumption and improved quality of the finished product.

To intensify the production of canned food for public catering, complex mechanised lines of low-operation technologies are being introduced, which eliminate manual labour and save 3.4–10% of vegetables and 1% of fat, significantly increasing labour productivity.

Technical re-equipment involves the commissioning of new facilities and the reconstruction of existing enterprises. Highly efficient imported lines and equipment complexes are being introduced, and the capacity for aseptic canning of semi-finished fruit products in large tanks is being increased.

Capacity expansion through the reconstruction of existing enterprises is the most effective use of capital investment. Vegetable drying plants are introducing recycling workshops to process waste into feed and technical products. More

efficient treatment facilities are being built. More advanced technologies are being developed for the production of both traditional and new products, characterised by high quality and environmental safety.

Every year, the canning industry generates about 20% of waste and by-products of the total volume of raw materials processed. Ways of rational use of by-products are shown in Tab. 10.7. (*infographic 5*).

Table 10.7. By-products and waste from the canning industry

By-products and Production Waste	Green Pea Vines and Pods, Husks, Peelings and Other Waste	Feed Meal		
		Livestock Feed (fresh or ensiled)	Used for drying and the production of compound feed	
	Potato Pulp and Peelings	Starch		
		Livestock Feed (fresh or ensiled)	Used for drying and the production of compound feed	
	Tomato Pomace and Seeds	Carotene		
		Vegetable Oil		
	Fruit and Berry Pomace	Alcohol Vinegar Food coloring Gelatin concentrates	Used as animal feed in its fresh form; for drying and the production of compound feed	
	Fruit Pits (Stones)	Kernel	Vegetable Oil Almond paste Oilcake	For the Confectionery Industry
		Shell	Furfural Activated Carbon Fuel Abrasive for grinding pastes	

All waste generated in the canning industry can be divided into three groups:

- waste that is processed at the same enterprise where it is generated;
- waste that is processed at other enterprises;
- waste that is used as feed for animals and poultry, as well as fertiliser.

The *first group includes waste* generated during the preparation of stuffed tomatoes, concentrated tomato products, and waste from various fruits used to make jams.

The second group includes: tomato seeds used for the production of vegetable oil; apricot, plum and other fruit pits used in confectionery production and for vegetable oil production; apple pomace from which pectin is extracted; pomace from coloured fruits and vegetables from which dyes are extracted; potato

peelings from which starch is extracted, etc.

The third group includes such waste as green pea pods and tops, corn cobs and leaves, cabbage, squash, eggplant, and pea waste. This waste is used as animal feed and fertilizer.

The amount of losses and the amount of vegetable and fruit waste during processing depends on the type of product being produced, the quality of the raw materials, their degree of ripeness, the production technology, and the degree of sophistication of the equipment used. The amount of waste in the production of canned fruits and vegetables ranges from 4 to 85%. During the processing of green peas, up to 85% of waste is generated, including tops and pods, potatoes – 35–45%, tomatoes – 30–40%, and during the production of canned snacks – about 12%.

During the production of tomato juice, about 65% of the raw juice and pulp is squeezed out. The remaining 35% is waste, 88% of which consists of pulp and juice and 12% of peel and seeds. The soluble solids content of this waste is 2.5–5%. The tomato pulp is used at the same factory after the skins and seeds have been separated to produce concentrated tomato products (tomato paste, tomato puree). The yield of raw tomato seeds is 1.2%, and dry seeds – 0.5% of the weight of the tomatoes being processed. Since the seeds spoil quickly, they are dried and sent to processing plants.

Dried tomato seeds are used for oil production, as well as for sowing or feeding poultry. During the production of tomato oil, waste is formed in the form of pomace, which contains, %: nitrogen-free extractive substances – 15–25; cellulose – 6–22; minerals – 5.3–6.3, including phosphorus – 1.0–1.4; calcium – 0.3–0.7; potassium – 0.4; sodium – 0.2; magnesium – 0.2; carotenoids – 1.7. Tomato pomace is a good feed for animals and a raw material for protein production. All tomato production waste is a valuable addition to animal and poultry feed. It enriches feed with proteins, fats, mineral salts and carotenoids. They are added to compound feed together with fruit and vegetable waste in an amount of 3–10%.

During the processing of green peas, waste in the form of tops and pods is produced. The yield of green peas is 15–20% of the harvested mass. The chemical composition of the tops is, % of dry matter: protein – 16; nitrogen-free extractive substances – 40; fats – 3; fibre – 30; minerals – 11; dry matter – 15–20, including up to 2% digestible protein. Green pea pods in the milky ripeness stage contain about 18% dry matter, including more than 6% sugar, 3% starch, 2.5% nitrogenous substances, 0.3% minerals, and 1% fibre.

Green pea waste is mainly used as animal feed in fresh, dried and silage form. It is also used to obtain, with the help of microorganisms, mycelium rich in protein and suitable for fattening animals. Green pea pods are used to make canned food, which increases the dry matter content of canned green peas. Green pea waste can be used as a nutrient medium for growing microorganisms that produce amylolytic or pectolytic enzymes, as well as for the production of flour, paste or acid hydrolysates.

During the production of canned vegetable snacks from eggplants and

zucchini, carrots, cabbage, and beets, waste is formed, which is mainly used as animal feed. Onion skins are used to produce food coloring. To preserve the biological value of this waste, it is dried in tunnel dryers. Carrot and beet waste is also used to produce alcohol, carotene, a nutrient medium for growing microorganisms, and food colouring.

In the process of producing food products from potatoes, during cleaning, 25 to 45% of waste is generated from the mass of raw materials from which they are produced. For every 7 tonnes of raw materials used to produce 1 tonne of dry potatoes, 8.4 tonnes of liquid waste containing about 5% dry matter are obtained. The chemical composition of liquid waste contains, % by weight of raw materials: starch – 56.8; nitrogenous substances – 0.59; fibre – 7.0; minerals – 15.5; soluble carbohydrates – 2.0; other substances – 18.1. The content of these substances can be increased by concentrating them (settling, centrifuging or drying). During drying, valuable concentrated feed is obtained in the form of flour or flakes, which contains 12% moisture and a large amount of proteins and minerals. For 1 tonne of dry feed, 18 tonnes of liquid or 4.5 tonnes of solid waste are consumed.

In the process of producing starch from potato waste, pulp with a dry matter content of 12–13% is obtained. The yield of pulp is about 40% of the weight of starch. Pulp contains 90–95% moisture, which complicates its storage and transportation. Therefore, it is dehydrated by thermal drying to a moisture content of 12%.

During the processing of seed fruits, a significant amount of waste is generated – pomace (when obtaining juice by pressing), pulp (when producing puree and juice with pulp), peel (when producing jam, compotes, marmalade). Waste from apples and pears accounts for 30–35% of the fruit's weight. The amount of peel relative to the adjacent layers of pulp is 48–51% in pears and 50–51% in apples of the total weight of waste. The content of pulp, peel and seeds in apples and pears is as follows: pulp – 37%; peel – 2.5%; seeds – 0.1–0.5%.

The waste from cleaning apples and pears is used to make puree, which is added in small quantities to the main product. High-quality oil can be obtained from apple and pear seeds. During the process of pressing juice from apples, waste in the form of pomace is produced in the amount of 34% of the raw material. Apple pomace contains 21–23% dry matter, including 4–5% sugar, 1.5–2.5% pectin, 5% fibre, and 0.2–0.4% organic acids.

Apple pomace is used to produce a gelling concentrate for the production of jam, marmalade, jam, jelly and other products. It is also used as one of the components of the nutrient medium for growing mould fungi in the production of pectolytic enzyme preparations. Vitamin B_{12} can be produced from apple pomace and alcohol stillage. Apple pomace is a good quality animal feed. Seeds from fresh apple pomace are good seed material for fruit nurseries.

The most effective way to use apple pomace is to produce pectin from it. The pectin content in apple pomace depends on the apple variety, the degree of ripeness, and the duration of storage, and ranges from 1.5 to 3.5% in raw pomace and up to 18% in dry pomace. For the production of pectin, the pomace is first dried or sulphited. The consumption of raw pomace to obtain 1 tonne of pectin is

about 70 tonnes. The secondary pomace formed during the production of pectin is pressed and used for animal feed.

Diagram of a Bulgarian production line for extracting pectin from apple pomace: 1 – crusher; 2 – conveyor; 3 – dryer; 4 – storage area; 5 – extractor; 6 – press; 7 – saccharification tank; 8 – pump; 9 – filter; 10 – collector; 11 – vacuum apparatus; 12 – pectin precipitation tank; 13 – Nutt filter; 14 – vacuum dryer; 15 – alcohol trap; 16 – ball mill.

In addition to apple pomace, apple processing also produces waste in the form of **sediment**. Sediment is formed during the separation, filtration and settling of juice. It consists of small particles of fruit tissue, coagulated colloidal substances, some insoluble compounds and sometimes yeast cells.

Chemical composition of the sediment, % of raw mass: dry soluble substances – 21.2; sugar – 10.1; organic acids – 0.6; nitrogenous substances – 3.0; tannins and dyes – 0.2; pectin substances – 1.0; mineral substances – 0.5. After separating the juice residues by separation, this sediment is used as feed and fertiliser.

During the production of compotes, jams, jellies, preserves, purees and juices from stone fruits, waste products are formed that contain seeds, skins, stems and pulp residues. The seeds are the most valuable.

Dried pits are processed at specialised plants, where the pits are *crushed to obtain pit dust***.** The latter is used to clean the metal covers of steam turbines and internal combustion engines, to manufacture furfural and activated carbon, and as fuel. Oil and almond paste are obtained from the kernels of the kernels.

The most rational use of pomace from dark-coloured fruits and berries (cherries, cranberries, rowanberries, sea buckthorn, raspberries, etc.) is the production of food colourings. The resulting colourings are used in the confectionery and food concentrate industries. Pomace is also used to produce fermented juices, raw alcohol and vinegar.

During the process of making juice from grapes by pressing, about 18% of pomace is formed, consisting of 43-45% skin with pulp residues, 22-23% seeds and 24-26% combs. Pomace contains about 5% sugar and 0.5% tartaric acid salts. In addition to pomace, about 4% of sediment is formed during centrifugation and aging of grape juice.

Grape pomace is also used to obtain seed material, oil, tannin, dyes (from dark-coloured grape varieties) and tartaric acid. Sugars are extracted from them and used in the production of yeast, alcohol and vinegar. Additional juice can be obtained from the sediment of grape juice, as well as tartar or tartaric lime.

10.6. Processing of raw materials and waste disposal in winemaking

The wine industry produces still wines (table, fortified and aromatised) and wines containing carbon dioxide (champagne, sparkling, effervescent or carbonated wine) from grapes. Varietal or blended fruit and berry wines, table wines, fortified wines, sweet wines and sparkling wines are obtained from the juices of fresh fruits and berries by alcoholic fermentation. The most commonly

used fruits and berries are apples, rowanberries, cherries, plums, raspberries, currants, strawberries, blueberries, cranberries, blackberries and cranberries. Juice intended for long-term storage is sulphited with sulphur dioxide and stored in hermetically sealed tanks.

Before fermentation, the juice is desulphurised. Cognac spirit is obtained from young wine materials with an alcohol content of 7–12% vol., sugar content of no more than 0.2%, and titrated acidity of at least 4.5 g/l. Champagne is mainly produced by semi-continuous and continuous methods under conditions of ultra-high yeast concentrations.

By-products and waste from winemaking include grape skins, grape pomace, seeds, carbon dioxide, various sediments (yeast, glue, etc.), cognac distiller's grains, and distiller's grains from the distillation of defective wines. These are valuable raw materials for the production of various products (Tab. 10.8., *infographic 6)*.

Table 10.8. By-products and waste from winemaking

By-products and waste from winemaking	Grape stems	Fertiliser, fuel, feed production
	Grape pomace	Alcohol, essential oils, fertilisers, vegetable oil, wine colouring agents, animal feed production
	Grape seeds	Tannin
	Yeast lees	Alcohol, animal feed production
	Grape marc	Wine sediment, tart wine, tartaric acid
	Broken glass	Glass recycling

Grape pomace usually contains 1–1.5% sugar and about 1% tartaric acid. Fresh ripe stems contain 1.6 to 3.2% enothanin, while green stems contain up to 5%, tannins up to 6%, as well as minerals (up to 2.4%) and nitrogenous substances. Tines are used as fertiliser or fuel, as well as for the production of silage, alcohol and pressed compost materials.

Grape pomace is similar in composition to the grapes from which the wine was made. In addition to sugars and alcohol, it contains nitrogenous, pectin, tannin and colouring substances, fats and fibre. The organic acids include tartaric, oxalic, malic, gluconic and citric acids. The mineral content is 1.2–3.6%, and the sugar content of the pomace is 30–50% of the sugar content of the grapes. Phosphorus and potassium prevail among the ash elements.

After pressing, the pomace is extracted with acidified hot water. After purification, the diffusion juice is neutralised with lime milk and calcium chloride. The resulting calcium tartrate precipitate is separated, dried and sent for the production of tartaric acid. The sugar-containing liquid is fermented. Raw ethyl alcohol is distilled from the mash and then rectified. The distillate of the mash after alcohol distillation is used as protein feed.

Extraction of red pomace for the purpose of obtaining food colouring is carried out after preliminary separation of the seeds. The resulting filtrate is filtered and evaporated under vacuum to 30% dry matter content. The result is a

syrup-like food colouring. With further evaporation and subsequent drying, a powdered food colouring is obtained.

After extraction, the pomace is pressed. The pressed liquid is returned for enrichment, and the pomace is dried. The peel is ground to obtain feed meal, which is used for animal feed along with other feeds. Granulated feed is obtained from the meal.

The pomace that has been stored and fermented is processed by direct distillation in addition to diffusion. For this purpose, it is subjected to direct distillation to obtain raw alcohol. After draining the stillage, the spent pomace is poured with an acid solution and boiled again. The resulting tartaric acid solution is neutralised with lime milk. Tartaric acid and its salts are produced from the resulting calcium tartrate.

Drying, separating grape seeds and obtaining grape oil from fermented pomace is carried out in the same way as with sweet pomace. The amount of waste after grape pressing depends on many factors: grape variety, region and soil and climatic conditions of cultivation, agricultural techniques used, processing technology, degree of grape ripeness, etc.

The yield of yeast sediment is 3–8% of the wine volume and depends on the degree of clarification of the must, the type of wine materials, the yeast strain, the content of assimilated nitrogen, the oxygen level, the amount of sugar in the must, the fermentation conditions, as well as the type of presses, crushers and drains used.

Yeast contains about 75% water and 25% dry matter. Dry matter contains, %: minerals – 5–10; carbohydrates (glucides) – 25–50; nitrogen – 4.8–12; protein – 30–75; and fats (lipids) – 2–5. The mineral part includes phosphates (50%) and potassium (25%). Yeast contains all known amino acids and vitamins. In addition to alcohol and tartaric acid salts, yeast sediments contain pectin, tannins and nitrogenous substances, dyes and protein substances and their compounds with tannin, silicon, fats, calcium and barium phosphates, sulphates and other compounds.

Through complex processing of the lees, it is possible to obtain raw alcohol, rectified alcohol, higher alcohols and aldehydes, enanthic ether (ester), dried yeast, yeast protein feed, calcium tartrate, tartaric acid and its salts. From 1 tonne of processed grapes, the yield of yeast sediment is 2–7 decilitres, or 15 kg of pressed sediment, excluding glue and bentonite sediments.

Comprehensive processing of grape pomace and wine yeast sediment from production waste also yields other secondary products: enanthic ether (cognac oil), tartar, calcium tartrate and other products. Grape seeds are separated from the washed and dried pomace. One tonne of grapes yields 20–21 kg of raw grape seeds, which are used in dry form to produce oil, feed meal and tannin. The oil content in the seeds is 10–20% of dry matter, depending on the grape variety, growing conditions and degree of ripeness. Grape oil and tannin are produced in the oil and fat industry.

During the storage of grape wine, tartar deposits form on the walls of the tanks in quantities of 5–20 kg per 1,000 decilitres. The most valuable products of

the complex processing of grape pomace and yeast sediments are tartaric acid and its salts, as well as ethyl alcohol.

10.7. Processing of raw materials and waste disposal in meat production

During the slaughter of animals and meat processing at meat processing plants and meat processing enterprises, a significant amount of various non-food waste is generated. They differ in their aggregate state, chemical composition and physical characteristics. However, what they have in common is the presence of animal protein, fat and mineral salts, i.e. everything that is essential for the intensive breeding of animals and poultry. In addition to their use as feed, meat processing plant waste is of great importance for the production of technical products that are widely used in the manufacture of consumer goods, soap making, woodworking, metallurgy and other industries.

The processing of meat production waste is also aimed at improving the environmental situation at enterprises and in the regions where they are located. This waste has a high moisture content and, due to the presence of protein substances, is a good breeding ground for the development of putrefactive microflora. Decay produces substances with an unpleasant odour (sulphur oxides, hydrogen sulphide, ammonia, mercaptans and lipid oxidation products). When they enter wastewater (fats, blood, offal, etc.), they enrich it with organic substances, which requires costly treatment. At the same time, the lack of proper treatment of such wastewater at the enterprise leads to the pollution of natural water bodies and the environment.

The multifaceted use of recycled waste requires the use of different technologies to obtain different end products from it. The use of low-waste and waste-free technologies for the disposal of non-food waste from meat processing enterprises is one of the necessary conditions for the organisation of modern production. The depth of processing and the range of products manufactured from waste depend on the capacity of the enterprise and the quality of raw materials, i.e. waste. Let us briefly consider the characteristics and directions of processing of this waste, the quantitative and qualitative indicators of the products being processed, resource conservation and reduction of negative impact on the environment.

Non-food waste from meat processing enterprises includes raw materials that are not intended for food or special purposes and are obtained in the process of processing animals, poultry, rabbits, horses and other animals; waste from the production of food, technical and special products at meat processing plants, poultry processing plants, canning and sausage factories, as well as at medical product factories; veterinary confiscates, animal and poultry carcasses that are approved by veterinary and sanitary supervision for processing for feed and technical purposes.

Waste from the processing of all types of animals includes: non-food trimmings from carcass trimming, raw fat, offal and skin removal; intestines that

are not used for the manufacture of intestinal products as casings for sausage production; intestine waste and sludge (serous, muscular and mucous membranes scraped from the intestines during processing), endocrine glands and eyeballs that are not collected for the production of medical preparations; gall bladders; udders of small ruminants and pigs; heart sacs, ears, limbs of small ruminants, boar skins, pieces of skins, loins, waste from skinning, edge pieces of cattle and pig skins, cattle tail roots, genitals, embryos without skins; blood of cattle and pigs not used for food purposes (whole blood, formed elements, fibrin), blood of small cattle, horses and other animals processed at meat processing plants.

At meat processing plants that process poultry and rabbits, as well as at meat processing enterprises that produce poultry meat products, non-food waste includes: feet, heads, intestines with contents and cloaca, glandular stomachs, spleen, goitres, tracheas, oesophaguses, stomach cuticles, oviducts, ovaries, testicles, gall bladders, lungs, kidneys, blood, low-value feathers and underwings, feather and down production waste, unformed eggs; poultry carcass trimmings. Rabbit processing waste includes blood, intestines, stomachs, heads, paws, and trimmings from skinning. Egg processing waste includes eggshells and technical defects in chicken eggs. Waste also includes raw fat that is not suitable for food purposes.

At factories producing sausages, canned food, edible fats, as well as in refrigerators, waste includes: cut stamps and non-edible trimmings, intestinal products and animal meat products (bones, cartilage, etc.), meat and bone sawdust, bone residue obtained after pressing bones, bones after deboning meat carcasses and heads of all types of livestock and poultry, tail bones, tendons, cracklings obtained after melting edible fats, fat after frying pies, etc.

Non-food waste also includes products from the processing of livestock of low nutritional value (sheep heads without tongues and brains, oesophagus, rumen, lungs, spleen, trachea, aorta, etc.) and veterinary confiscates (carcasses and parts of carcasses and organs of livestock and poultry, meat of wild animals, as well as meat and by-products from the forced slaughter of livestock and poultry); non-food raw materials include carcasses of livestock and poultry that have died in meat processing plants and poultry farms, which are approved by veterinary and sanitary supervision for processing into feed products.

Fatty raw materials include: rejected meat and internal organs of animals that are not used for food purposes, low-value products from the slaughter of livestock, cracklings from the rendering of edible and technical raw fat, embryos and reproductive organs, intestines and intestinal waste products, sludge, endocrine glands and eyeballs, gall bladders, udders of small ruminants and pigs, heart sacs, and waste from the processing of rabbits and poultry.

Collagen-keratin-containing raw materials include horns and hooves of all types of livestock, waste from horned livestock, low-value feathers and underwings, waste from feather and down raw materials, boar skins, edge sections of cattle and pig skins, tendons and other waste.

Non-food waste from meat processing plants is rich in organic and mineral substances. Organic substances include proteins, fats, carbohydrates and vitamins.

Proteins are nitrogen-containing organic substances that can break down into amino acids.

Lipids (fats) are organic substances that are generally insoluble in water and soluble in hydrophobic solvents. Animal fats are complex esters of triatomic alcohol, glycerol and higher fatty acids. The triglycerides of animal fats include saturated and unsaturated (oleic, linoleic, linolenic, arachidonic) fatty acids. Fat is a mixture of triglycerides that differ in their fatty acids, their quantitative ratio and structure. Animal fats are rich in palmitic, stearic and oleic acids. Their glycerol content is 10%. In addition to fats, the lipid group also includes associated fat-soluble substances: phosphatides, serines, lipochromes – pigments and vitamins.

Non-food waste is rich in mineral salts (macro- and microelements). Microelements include calcium, phosphorus, potassium, sodium, chlorine, sulphur, magnesium, and microelements – zinc, copper, manganese, iodine, molybdenum, cobalt, selenium, fluorine and iron. The highest concentration of microelements (mainly phosphates and calcium carbonates) is found in bones.

Non-food waste also contains water-soluble and fat-soluble vitamins. Water-soluble vitamins include B_1(thiamine), B_2(riboflavin), C (ascorbic acid), H (biotin), B_3(pantothenic acid), B_{12} (cobalamin), PP (nicotinic acid), B_6 (antidermatitis), B_9 (folic acid), choline, para-aminobenzoic acid; fat-soluble vitamins – vitamins A (retinol anti-xerophthalmic), D (anti-rachitic), E (tocopherol), K (anti-haemorrhagic), F (essential fatty acids).

Non-food waste also contains carbohydrates, mainly glycogen, glucose and glycosaminoglycans. Carbohydrates in the form of monosaccharides (glucose and fructose) are found in blood; heparin is found in the form of glycosaminoglycan. It is abundant in the lungs, liver, heart and skeletal muscles.

The average chemical composition of bones of cattle of average fatness contains, %: moisture – 40, fat – 19, mineral salts – 23 and protein – 18. Fat mass, which is extracted from industrial wastewater, is also a raw material for technical processing into feed products. Various types of feed and technical products are produced from non-food products.

Among feed products, animal meal is of the greatest importance, as it is a source of protein in compound feed for farm animals and poultry. In addition to meal, the following are produced: feed protein concentrate, feed semi-finished products, feed precipitate, bone meal for poultry feeding, dry protein-vegetable feed, protein-fat concentrate, etc., feed precipitate and semi-finished bone products are produced at gelatin and glue factories during bone processing.

The following types of animal-derived meal are produced: meat meal, bone meal, meat-and-bone meal, blood meal, and hydrolysed feather meal. Meat-and-bone meal is mainly produced from pulp and meat-and-bone non-food raw materials and bones of slaughtered animals. The raw materials may also include other non-food waste. Meat and bone meal contains 30 – 50 % protein and 13 – 20 % fat. Meat meal differs from meat and bone meal in that it contains less bone in the raw materials, has a higher protein content (at least 64%) and a lower mineral salt content (11% instead of 26–38%).

Blood meal is produced from blood, blood cells and fibrin with the addition of a small amount of bones. It is distinguished by its high protein content (not less than 81%) and the highest content of iron in an absorbable haem form. It is mainly used for fattening young animals and poultry.

Bone meal is produced from all types of dry defatted bone and bone residue obtained by mechanical grinding of meat. Its minimum protein content is 20%. Its level in flour is determined by the production technology. When using a technology that prevents protein breakdown and is characterised by minimal losses, the protein content is between 32 and 38%. Bone meal has a significant content of phosphorus and calcium salts, which is why it is mainly considered a mineral component of compound feed.

Feed semi-finished products are made from moulded elements of edible blood, hydrolysate of keratin-containing raw materials and broth obtained during the production of edible bone fat in autoclaves and vacuum boilers. It contains at least 75% protein and no more than 5% fat and is used in the production of compound feed and feed mixtures to obtain substitutes for whole milk, which is used to feed calves and piglets.

Protein-fat concentrate is obtained by drying the emulsion in spray dryers. The emulsion consists of broth from the melting of edible bone fat, which is not used for food purposes, in autoclaves and vacuum boilers, as well as hydrolysate of keratin-containing raw materials, feed or technical grade I fat. Broth from the production of dry animal feed in vacuum boilers is also used to make the concentrate. Protein-fat concentrate is used in the production of compound feed as an energy enhancer, since it contains 50% fat and at least 30% protein.

The feed enhancer is produced from the contents of the forestomachs of cattle through sterilisation and drying. At a moisture content of 5%, it contains 18.5% protein, 4% fat, 28% fibre, 18% ash and 5% nitrogen-free extractive substances. Feed enricher is distinguished by its high content of B vitamins (mainly B_{12}). It is used for fattening pigs.

Feed protein concentrate is produced from keratin-containing raw materials (horns, hooves, poultry feet) using urea. It contains 73–81% protein, 1.5–4% fat, and 7–13% mineral salts. It is added to compound feed for large and small cattle – up to 8%, for pigs – up to 4% and for poultry – up to 3%.

Feed precipitate is produced during the demineralisation of bones at gelatin factories. It contains large amounts of phosphorus and calcium salts and is used as a mineral supplement for animals and poultry, especially young animals.

Glue factories produce bone meal for feeding poultry from defatted and deglutted bones, as well as from waste from polishing meal in the form of small bones and separated pieces of pulp tissue. The meal has a low protein content (about 13%) and fat content (4%), but has a significant phosphorus and calcium content.

Dry protein-vegetable feed is produced from the contents of the forestomach of cattle, horns, hooves, edge pieces of hides, boar hides, hide waste, bones of all types of animals in raw and defatted form, technical blood, fibrin and formed elements of edible blood. It contains at least 30% protein, no more than 20% fat,

20% fibre and at least 20% mineral salts. This feed is used to feed pigs.

Horn and hoof meal is produced from raw materials that do not meet the requirements for horns and hooves used in the manufacture of consumer goods. Hair, wool and bristles may be used for this meal. It has a high protein content (at least 12% nitrogen) and low fat content (6%). This meal is used as a feed additive in the production of dry animal feed and as an inhibitor of acid corrosion during digestion.

Cooked (wet) feed and feed broth are obtained from all types of non-food waste from meat processing enterprises, with the exception of keratin-containing waste, including waste from feather production, which has wool and hair cover, as well as eggshells.

Wet feed is a feed product that is unstable during storage, characterised by a high (up to 80%) moisture content and low protein and fat levels (about 5%). Such feed must be used in a timely manner. Otherwise, it is treated with a non-toxic preservative to ensure longer satisfactory storage.

Feed broth is obtained during the cooking and sterilisation of meat products (bones, offal, meat and bone waste). It has a low dry matter content (not less than 4%), 1% fat and no more than 1% salt. It is a perishable product and therefore must be stored at a temperature not exceeding 6 ^{0}°C. It is mainly used for fattening pigs.

Feed fat is obtained in the process of processing non-food waste into feed products. It is used as an energy source in compound feed, as well as for the production of certain types of feed products, in particular protein-fat concentrate. Its introduction into the diet of pregnant sows reduces piglet mortality by 18%, shortens fattening periods, and increases live weight gain. In the case of poultry fattening, it increases growth intensity and disease resistance.

Technical products made from non-food waste include technical albumin, technical fat, acid corrosion inhibitor and foaming agent. Black technical albumin is produced from defibrinated or finely ground whole technical blood and formed elements of edible blood when it cannot be used for food production or for medical and preventive purposes. It is used in the production of glue for woodworking.

Technical fat, like feed fat, is obtained in the process of processing non-food waste into feed products and is used in soap making, the production of fatty acids and glycerine, consistent lubricants, lubricating and cooling fluids, defoamers, etc. PU-6 (PO-6) foaming agent is produced from whole technical blood of all types of slaughtered animals. Acid corrosion inhibitor is used during chemical etching of metals. Meat and bone meal, blood meal and bone meal are used for its production. The inhibitor must contain at least 55% protein and no more than 25% fat with a moisture content of no more than 10%.

Questions for discussion and self-assessment

1. What is the purpose of comprehensive processing of raw materials in the food industry?
2. What waste is produced in the process of producing sugar from beet?
3. How are sugar beets processed?
4. Explain the difference between rational processing of raw materials and comprehensive processing.
5. How is pulp utilised in sugar production?
6. Processing of raw materials in the production of ethyl alcohol.
7. How is waste utilised in the alcohol industry?
8. How is molasses used in alcohol factories?
9. How is wastewater treated at alcohol factories?
10. Describe the processing of raw materials in the production of sunflower oil.
11. How is waste disposed of in the oil and fat industry?
12. How is comprehensive processing of raw materials carried out in starch and syrup production?
13. How is gluten disposed of in starch production?
14. What waste is generated in canning production and how is it disposed of?
15. How are apple pomace disposed of?
16. Describe the production of pectin from apple pomace.
17. What waste is generated in winemaking and how is it utilised?
18. Describe the processing of raw materials at meat processing plants.
19. What waste is generated at meat processing plants and how is it disposed of?
20. What is non-food waste from the meat industry and how is it disposed of?

11.1. Sources of atmospheric air pollution

Atmospheric air is the environment in which living organisms – plants, animals, humans and microorganisms – exist. It provides humans, plants and animals with essential gases (oxygen, carbon dioxide) and protects the earth from meteorites, cosmic radiation, etc.

The atmospheric air in the lower layers of the troposphere consists mainly of nitrogen, oxygen, argon and carbon monoxide (IV) (Tab. 11.1). Small amounts of neon, helium, krypton, xenon, nitrogen (II) and (IV) oxides, hydrogen, methane, ozone, carbon (II) oxide, ammonia, etc. are also present.

Table 11.1. Chemical composition of atmospheric air

Component	Content, %	
	by mass	by volume
Nitrogen	72.5	78.09
Oxygen	23.15	20.94
Argon	1.28	0.93
Carbon (IV) oxide	0.046	0.033
Neon	0.0012	0.0018
Helium	0.00072	0.00052
Krypton	0.00033	0.0001
Xenon	0.000039	0.000008
Nitrogen oxide (II)	0.0025	0.00025
Hydrogen	0.0000035	0.00005
Methane	0.0008	0.00015
Nitrogen oxide (IV)	0.00008	0.000015
Ozone	-0.000001	0.000002
Sulphur (IV) oxide	—	0.000002
Carbon (II) oxide	—	0.00001
Ammonia	—	0.000001

Atmospheric air is one of the main natural resources, without which humans can only survive for a few minutes. Humans do not have protective mechanisms that compensate for a lack of air, so they must consume 8–10 litres per minute and 12,000 litres (15 kg) per day of fresh air in a calm state. The human body has adapted to clean air, so it always needs it to be clean with consistent properties, chemical composition, speed of movement and ionisation.

Atmospheric air is used in industry as:

- a reagent for fuel combustion;
- a heat transfer medium for heating and cooling products, equipment and premises;
- an oxidant for many chemical and biochemical processes, etc.

The activities of food enterprises result in the pollution of atmospheric air, which leads to changes in its chemical composition and physical and physicochemical properties.

Atmospheric pollution is understood as the introduction of gaseous, liquid and solid substances into the atmosphere in excessive quantities. In general, *atmospheric pollution* refers to unfavourable changes in the state of atmospheric air, wholly or partly caused by human activity, which directly or indirectly affect the distribution of incoming energy, chemical composition, radiation levels, physicochemical properties of the atmosphere and the conditions of existence of living organisms.

According to the Law of Ukraine "On the Protection of Atmospheric Air", atmospheric air pollution is understood as a change in the composition and properties of atmospheric air as a result of the introduction or formation of physical, biological factors and (or) chemical compounds that can adversely affect human health and the state of the natural environment.

Air quality standards are the maximum permissible values of pollutant content in the air, at which there is no negative impact on human health and the environment.

Emissions into the atmosphere by food enterprises are divided into the following groups:

- emissions resulting from the release of energy and heat by vehicles with internal combustion engines;
- emissions associated with basic technological processes;
- emissions from workshops processing secondary material resources;
- emissions from auxiliary workshops and production facilities.

The sources of emissions in the first group at enterprises are boiler rooms, steam power equipment, furnaces and motor vehicles. Gas, fuel oil and solid fuel (coal) can be used as fuel. The specific emissions of air pollutants during the combustion of different fuels depend primarily on the type of fuel. The largest amount of pollutants is emitted during the combustion of solid and liquid fuels. During the combustion of 1 tonne of coal, up to 23 kg of ash, 15 kg of sulphur (IV) oxide and a significant amount of soot are emitted into the atmosphere. In addition to carbon oxides (CO_2 and CO), sulphur oxides, nitrogen oxides and soot are formed during combustion. During the transportation of coal, coal dust enters the atmosphere (Fig. 11.1).



Fig. 11.1. Emission of hazardous substances into the atmosphere [2]

Exhaust gases from motor vehicles contain more than 200 harmful compounds, including about 4–5% carbon monoxide (II), as well as unsaturated hydrocarbons and aldehydes with an unpleasant odour, sulphur-containing compounds and lead compounds in the case of leaded petrol. They also contain carcinogenic compounds. A passenger car emits up to 3 m³ of CO per hour while driving, and a truck emits 6 m³ or more (Fig. 11.2).



Fig. 11.2. Exhaust gases from motor vehicles [3]

As in other industries that are sources of atmospheric pollution, the food industry emits solid, liquid and gaseous substances.

However, pollutants such as sulphur oxides, carbon oxides and nitrogen oxides are not typical, except for emissions from auxiliary systems (boiler rooms, can production, glassware, etc.). The problem of emissions in the food industry is more related to dust and odorous substances.

Many technological processes involve the processing of bulk products such as grain, flour, sugar, starch, table salt, tea, coffee, etc.

One of the main problems is dust removal from grain mills and elevators during grain drying, as well as during the production of dry milk, casein, etc. (Fig. 11.3).



Fig. 11.3. Elevator [4]

Many industrial processes of cooking, frying, and smoking are associated with the emission of large amounts of dust and odorous substances (oil extraction, smoking of meat and fish, drying of fish, etc.). Very often, emissions are «masked» by steam, which is formed in the same processes. There are a number of food enterprises where odours are emitted without visually observable pollution (spray drying, fish processing, tomato cooking, etc.). Data from American researchers on emissions into the atmosphere after technological processes in the absence of suppression are presented in Table 11.2.

The purpose of many processes is to grind solid substances into a powdery state (e.g., grinding grain to obtain flour and cereals). In other cases, the material is partially pulverised due to the characteristics of the technological process (imperfection of technological equipment and characteristics of the raw materials being processed). Significant grinding occurs during the transportation of materials due to friction against the walls of pipelines in the pneumatic transport system, in the event of overloads, etc.

Table 11.2. Aerosol content after technological processes in the food industry (including heating)

Technological operation	Emissions in the absence of suppression	
	Aerosols, mg/m^3	Turbidity*, %
Smoking: sausages	1.6	50
bacon (periodic)	2.5	40
Peanut oil pressing	4.55	40
Roasting: coffee (periodic)	6.5	20–80
peanuts	9.4	40
hamburgers	16	60

*Turbidity of emissions – attenuation of visible radiation, expressed as a percentage.

These losses can be quite high, reaching 1–2% or even more. For example, during the production of tobacco products, up to 2% of the tobacco that enters production is crushed and turned into dust, which reduces the yield of usable products and pollutes the environment.

The meat and dairy industries are particularly polluting to the atmosphere. They have various sources of pollution:

- emissions from general and local ventilation systems;
- gaseous emissions from technological equipment;
- substances with an unpleasant odour;
- organised and unorganised emissions;
- emissions from motor vehicles, etc.

The volume and composition of emissions depend on the source of their formation and transport (organised or unorganised emissions, type of ventilation, etc.).

The main sources of atmospheric pollution in the meat industry are technical and food production workshops, thermal emissions from sausage factories, food fat processing and albumin production departments, water treatment facilities, auxiliary workshops, etc. Ventilation emissions contain ammonia, phenols, ketones, hydrogen sulphide, sulphur dioxide, carbon oxides, soot, wood and bone dust, etc. Depending on the capacity and technological features of production, the amount of ventilation air emitted and the concentration of harmful substances vary widely.

In addition to gaseous harmful substances, various technological processes in meat processing enterprises generate a lot of dust, which is emitted into the atmosphere by exhaust ventilation systems. Such production facilities include smoke generators, glue departments, boiler rooms, medical product manufacturing, corrugated packaging workshops, etc. (Table 11.3).

Table 11.3. Sources of dust emissions at meat processing plants

Production (equipment)	Solid particles (dust)	Concentration, mg/m^3
Technical products workshop, grinding department	Meat and bone	17*; 14 – 76
Albumin department	Albumin	3 – 10
Elevator loading	Meat and bone	14 – 45
Sausage production Smoking chamber	Resinous	7.8 – 47
Shacht furnaces	Resinous	7.7 – 9.1
Spice packaging	Pepper	36.8 –160
Enzyme department, medical preparations workshops	Haemostimulin	6
Consumer goods workshops	Lysates Pepsin Bone	3.6 – 148.6 41 0.3 – 106
Corrugated packaging	Paper	0.17 – 21 1 – 15*

*In ventilation air or process gases after dust removal systems before discharge into the atmosphere.

At meat processing plants, the main sources of atmospheric air pollution with unpleasant-smelling substances are technical and feed product workshops, where waste from the main workshops (meat and fat, sausage, canning, etc.) is processed.

Due to the leakage of equipment in the raw materials department, a significant amount of substances with an unpleasant odour are released into the air, mg/m^3: ammonia – 2.27 – 7; hydrogen sulphide – 2.4 – 0.04; phenols – 7 – 0.5; mercaptans – 1; ketones – 13 e – 8; aldehydes – 36 – 0.06. The amount of pollutants depends on the freshness of the raw materials and the technological operation. When transferring raw materials from one apparatus to another, the seal is broken and there is a sharp increase in odour.

During the preliminary roasting of raw materials (pig heads, ears, cow lips and ears), 1.2 to 15.6 mg/m^{3}of substances with an unpleasant odour are released. The volume of gases emitted after the roasting ovens, depending on the type of raw materials being processed, is 1110–3450 m^3/hour with a moisture content in the waste gases of 10.9–25.6 g/m^3. Organised emissions from technical equipment account for about 10–30% of total emissions from enterprises: juice vapour from vacuum evaporators, smoke from smokehouses, and air emissions from dryers. Despite their insignificant quantity, the concentration of pollutants in them is the highest.

Emissions from exhaust ventilation systems contain insignificant concentrations of pollutants. However, this is the largest (70–90%) emission of pollutants containing various gaseous and vapour-like substances and dust.

The volume of emissions into the atmosphere depends on the specifics of the production technology, the design of the installed equipment, the reliability of ventilation systems, meteorological conditions and many other factors. Depending on the capacity of the enterprise, the total volume of emissions can range from 50 to 300 thousand m^3/hour.

The main sources of atmospheric pollution in the dairy industry are:

- production of dry milk and dairy products (dryers, fire heaters);
- tin can workshop (tinning, lacquering, etching, soldering);
- casein production (crushers, casein dryers);
- container and equipment washing department;
- ice cream production (wafer baking oven);
- cheese factories, paraffin wax factories, smoked sausage factories, etc.

During the production of dry milk and dairy products, dust from dry products accounts for 500–^{3},000 mg/m^3 of emissions. Emissions from fire heaters include nitrogen oxides, sulphur dioxide and carbon oxides. Emissions from the tin can workshop contain 0.1–4.5 mg/m^3 of metal dust, as well as tin vapour and organic substances. Emissions from the cardboard and printing workshop contain lead aerosol, 1.5–2 mg/m^3 of paraffin vapour, 400–500 mg/m^3 of ethyl alcohol and traces of formaldehyde and ethylene oxides. Emissions from the cheese-making workshop (after the paraffin wax machine) and the smoked cheese workshop contain, mg/m^3:

- paraffin vapours – 1–5;
- nitrogen oxides – 0.1 – 0.9;
- sulphur dioxide – 4 – 20;
- carbon oxides – 70–200;
- soot – 27–54;
- ammonia – 0.1 – 1.2.

During the washing of containers and equipment, alkali vapour is formed in an amount of 0.07–0.6 mg/m^3 and acid vapour in an amount of 0.1–1.0 mg/m^3. The following substances are released into the atmosphere at water treatment facilities:

- hydrogen sulphide in the amount of 0.1–30 mg/m^3;
- ammonia – 2–50 mg/m^3;
- methane – up to 1%;
- chlorine vapours – 0.05–0.5 mg/m^3.

At bakeries, specific organised emissions include flour and sugar dust, waste gases from compressor-air installations used for aerosol transport of flour. During dough fermentation, carbon dioxide, ethyl alcohol, aldehydes and complex ethers are released. Flour dust is released during the reception, storage, dosing and technological transportation of flour. Flour losses in this process reach 0.2%.

Carbon dioxide is released in the liquid yeast preparation department. Large bakeries usually build boiler rooms to provide steam, hot water and heat for technological operations. Fuel combustion products are hazardous to the environment. They are typical for all boiler rooms, and their composition depends on the type of fuel (coal, wood, liquid fuel, natural gas). The composition of

atmospheric air pollutants from the wood-fired boiler room of the Mostivsky canning factory is presented in Table 11.4.

Table 11.4. Harmful substances emitted into the atmosphere by the boiler room of the Mostivsky canning factory

Substance	GC_{mr}, mg/m³	GC_e, mg/m³	Hazard class	Emissions of substances	
				g/year	tonnes/year
Ash	0.5	0.15	3	0.612	2.329
Soot	0.15	0.05	3	0.0032	0.00185
Sulphur dioxide	0.5	0.05	3	0.708	0.650
Nitrogen oxides	0.085	0.04	2	0.142	1.050
Carbon oxide	5	3	4	1,742	12.246

During alcohol fermentation at alcohol plants, large amounts $_{of\ CO_2}$ are released, some of which is utilised, but most of which is emitted into the atmosphere.

In the oil and fat industry, raw materials are blown with air before storage, which after air separators contains 5 – 8 g of dust per 1 m³. During storage, raw materials are ventilated with air mixed with flue gases. Ventilation air from storage facilities contains volatile products of metabolism of raw materials, carbon dioxide formed during respiration, and small dust particles. Dust is also formed during the process of separating the husks from the grain. At the stage of extraction of pressed cake, volatile substances (petrol, hydrocarbons, alcohols, ketones) are released into the atmosphere. During the processing and drying of meal, residues of raw materials and extraction reagents may also be released into the atmosphere.

Industrial wastewater and waste from food production enterprises are significant sources of atmospheric pollution. When they enter the environment, they decay and transform into secondary pollutants, in particular gaseous and volatile compounds that enter the atmosphere. These can be hydrogen sulphide, carbon disulphide, ammonia, methane, mercaptans and other toxic substances with an unpleasant odour.

11.2. Classification of industrial air pollution

Industrial emissions into the atmosphere are classified according to:

- *disposal and control organisation* – organised and unorganised;
- *temperature of exhaust gases* – heated, whose temperature is higher than the temperature of atmospheric air, and cold;
- *localisation* – main, auxiliary and ancillary production;
- *purification characteristics* – emissions without purification (organised and unorganised) and after purification (organised). Gas purification is understood as the separation of pollutants from the gas flow or their conversion into a harmless state.

Organised industrial emissions are emissions that are discharged into the atmosphere from their points of origin by a system of flues and air ducts (chimneys, shafts, general exchange and ventilation systems). *Unorganised* emissions are emissions that enter the atmosphere in the form of uncontrolled gas flows due to equipment leaks, the absence or unsatisfactory operation of gas extraction equipment at product loading, unloading and storage sites, as well as through skylights in workshop premises, window and door openings. These can be emissions of gases, vapours, dust and spills of volatile compounds.

Industrial emissions into the atmosphere are divided into primary and secondary. *Primary* emissions are those that enter the atmosphere directly from the source, while *secondary* emissions are products of primary emissions, but may be more toxic and dangerous than primary emissions (e.g., the transformation of certain substances as a result of photochemical oxidation).

All sources of atmospheric pollution by industrial emissions can be classified, in particular, according to the following criteria:

- purpose:
  - *technological,* consisting of tail gases after capture at installations, purging of apparatus and air extractors;
  - *ventilation emissions* – local extraction from equipment and general exhaust;
- location:
  - *unshaded* or *high,* located in an area of undistorted wind flow (high pipes and point sources that remove pollution to a height greater than 2.5 times the height of the building);
  - *shaded,* or *low,* located at a height less than 2.5 times the height of the building;
  - *ground-level,* located close to the earth's surface (open equipment, sewer wells, spilled toxic substances and industrial waste discharges);
- by geometric shape:
  - *point sources* (pipes, shafts, roof fans);
  - *linear* (ventilation lights, open windows, closely located exhaust shafts and torches);
- operating mode:
  - *continuous* and *periodic, salvo* and *instantaneous*. Burst emissions are possible during accidents and the incineration of fast-burning production waste at special disposal sites, while instantaneous emissions are released within fractions of a second, sometimes to considerable heights. They occur during demolition work and accidents. These emissions are particularly dangerous for the air environment;
- location:
  - *on-site,* when pollutants released into the atmosphere remain in high concentrations in the industrial zone, while no pollution is observed in residential areas;
  - *off-site,* when they can cause significant air pollution in residential areas.

Pollutants are classified according to their toxicity into four classes depending on the degree of poisoning hazard: extremely hazardous, highly hazardous, moderately hazardous and low hazardous (Table 11.5).

Table 11.5. Classification of substances according to the degree of danger

Toxicity indicator (established experimentally or approved by a regulatory body)	Hazard class standard for substances			
	Extremely dangerous (1)	Highly hazardous (2)	Moderately dangerous (3)	Low-hazardous (4)
MPC of the working area, mg/m^3	< 0.1	0.1 – 1.0	1.1 – 10.0	> 10.0
Average lethal dose, gastric administration, mg/kg	< 15	15 – 150	151 – 5000	> 5000
Average lethal dose, intradermal, mg/kg	< 100	100 – 500	501 – 2500	> 2500
Average lethal concentration, inhalation, mg/m^3	< 500	501 – 5000	5001 – 50000	> 50,000
Potential poisoning coefficient	< 300	300 – 30	29 – 3	< 3
Acute action zone	< 6.0	6 – 18	18.1 – 54	> 54
Chronic action zone	> 10	10 – 5	4.9 – 2.5	< 2.5

11.3. Characteristics of atmospheric pollutants and their environmental impact

The main atmospheric pollutants that enter the atmosphere each year include, million tonnes/year:

- sulphur dioxide and dust – 200;
- nitrogen oxides (N_xO_y) – 60;
- carbon oxides (CO and CO_2) – 8000;
- hydrocarbons (C_xH_y) – 80.

Sulphur dioxide (SO_2), or sulphur gas, is formed during the combustion of fuels containing sulphur impurities (coal, fuel oil, natural gas) in boiler rooms, dryers and other furnaces. At high concentrations in the atmosphere, plants quickly lose chlorophyll, cells rupture and tissue necrosis occurs, turning brown. The most sensitive plant species, such as alfalfa, soybeans and barley, show symptoms of damage at concentrations of sulphur dioxide of around 0.3–0.5 million^{-1} for a duration of at least 2–3 hours. In the case of more intense exposure to sulphur gas, almost complete necrosis of young coniferous trees may be observed, resulting in their complete defoliation. Sulphur (IV) oxide and its other compounds irritate the mucous membranes of the eyes and respiratory tract. Prolonged exposure to low concentrations of this gas leads to chronic gastritis, hepatopathy, bronchitis, laryngitis and other diseases. There is evidence of a link between the content of sulphur dioxide in the air and the mortality rate from lung cancer.

Sulphur trioxide (SO_3) is formed by the oxidation of sulphur dioxide in the

atmosphere during photochemical and catalytic reactions and is an aerosol or solution of sulphuric acid in rainwater.

Sulphuric acid, falling with atmospheric precipitation (rain, snow, hail), acidifies water in surface reservoirs and soils, intensifies corrosion of metals, destruction of rubber, marble, limestone, dolomite. It exacerbates diseases of the pulmonary system and respiratory tract in humans and animals. Sulphur dioxide is common in areas with thermal power plants, boiler rooms and dryers and is very harmful to plants, as it is easily absorbed by them and disrupts their vital functions.

Hydrogen sulphide (H_2S) and *carbon disulphide* (CS_2), are emitted into the air at sugar factories, sewage treatment plants and other places where anaerobic processes of organic matter transformation by microorganisms take place (bottom sediments of rivers, swamps, lakes and seas in ports and areas of contaminated water runoff from land, in city sewage networks). A characteristic feature of these pollutants is their sharp, unpleasant, irritating odour and high toxicity (they are 100 times more toxic than sulphur gas). In the atmosphere, hydrogen sulphide slowly oxidises to sulphur anhydride according to the following scheme

$$H_2S + 2O_2 = SO_3 + H_2O$$

Sulphate-reducing bacteria split oxygen from sulphuric acid molecules and its compounds contained in effluents and stagnant waters (effluent ponds, sludge storage facilities, etc.) and release hydrogen sulphide. If the latter forms black sulphide compounds, it is not harmful. Free hydrogen sulphide is very dangerous. It has a pungent smell of rotten eggs and dissolves well in water. This gas is easily absorbed by the mucous membranes of the eyes, nose and respiratory tract. In significant quantities, it severely irritates these organs, corrodes them, leads to inflammation of the trachea, bronchi, lungs and even death. Prolonged exposure to low concentrations of hydrogen sulphide causes skin irritation, rashes and boils. One or two inhalations of high concentrations of the gas cause paralysis of the respiratory organs and death. Carbon disulphide affects the nervous system, causing acute intoxication and the development of atherosclerosis.

Carbon monoxide (II) CO, or carbon monoxide, is colourless and odourless and is one of the most common air pollutants. It is formed by incomplete combustion of fuel according to the reaction

$$2C + O_2 = 2CO$$

The largest source of carbon monoxide in cities is motor vehicles. Complete combustion of fuel leads to the formation of CO_2 according to the reaction

$$C + O_2 = CO_2$$

Carbon monoxide (II) in the atmosphere is oxidised by oxygen in the air to CO_2 according to the reaction

$$2CO + O_2 = 2CO_2$$

The accumulation of carbon dioxide in the atmosphere contributes to the development of the greenhouse effect. At a concentration of more than 1% in the air, CO has a negative effect on plants, animals and humans, and at more than 4% it causes death. The toxicity of carbon monoxide lies in the fact that when it enters the bloodstream, it deprives red blood cells of their ability to transport oxygen, leading to oxygen deprivation, suffocation, dizziness and even death. It causes cardiovascular disorders and leads to the development of atherosclerosis.

Nitrogen oxides (N_xO_y) – N_2O, NO, N_2O_3 , NO_2, N_2O_5 are much more dangerous to humans than carbon monoxide (II). They are formed as a result of imperfect fuel combustion technology in thermal units. Therefore, they are abundant in areas with thermal power plants, boiler rooms, and dryers. They can also be formed in internal combustion engines. When combined with water in the respiratory tract, nitrogen oxides form nitric and nitrous acids, which cause severe irritation of the mucous membranes and serious diseases.

Nitrogen oxide (I) N_2O has narcotic properties and is used during surgical operations.

Nitrogen oxide (II) NO affects the human nervous system, causing paralysis and convulsions, binding haemoglobin in the blood and causing oxygen starvation.

Nitrogen oxides NO_2 and N_2O_4 react with water to form nitric acid according to the reaction

$$4NO_2 + 2H_2O + O_2 = 4HNO_3,$$

which leads to damage to the respiratory tract and pulmonary oedema. Nitrogen oxides are involved in the formation of photochemical smog. Photochemical processes include the formation of peroxyacetyl nitrates (PAN). At PAN concentrations of 0.1–0.5 mg/m^3), they can cause irritation of the mucous membrane of the eyes and plant death. A higher number of upper respiratory tract diseases is observed in populations exposed to high levels of nitrogen oxides. People with chronic respiratory diseases (pulmonary emphysema, asthma) and cardiovascular diseases are more sensitive to the direct effects of nitrogen oxides.

Toxic hydrocarbons (paraffins, naphthenes, aromatic hydrocarbons, benzopyrene, etc.) are the products of incomplete fuel combustion emitted by internal combustion engines. They are also formed during certain technological processes in the food industry. Unsaturated (olefin) hydrocarbons, which account for 35% of total hydrocarbon emissions, are extremely harmful. Hydrocarbon compounds cause the formation of smog – photochemical fog – in large cities. Summer sunny days with no wind are favourable conditions for the formation of smog. Hydrocarbons irritate the respiratory tract, causing nausea, dizziness, drowsiness, and respiratory and circulatory disorders. Some hydrocarbons are carcinogens.

The effect of dust emitted into the atmosphere on the human body is related to its dispersibility, chemical composition and other physical and chemical properties. The degree of dispersion of solid particles in the air affects both their properties (volatility, solubility, electrical and optical properties, etc.) and the

depth of their penetration into the respiratory organs and retention in the lungs. If the size of the particles is more than 10 μm, they settle at an increasing rate as their size increases. If their size is between 0.1 and 10 μm, they settle at a constant rate. Dust particles smaller than 0.1 micrometres do not settle at all and are in constant Brownian motion.

Hygroscopic particles are capable of coagulating and increasing in size. Deep breathing, for example during significant physical exertion, increases the degree of dust retention in the lungs. Irregularly shaped particles settle more slowly. Spherical particles are more easily absorbed in the lungs. Particles with sharp edges can cause microtrauma to the respiratory epithelium, disrupt its barrier function, and promote the penetration of microorganisms and the development of pneumoconiosis.

Most solid particles carry a negative or positive charge, which increases their ability to remain in the lungs. The biological activity of dust, in particular its allergenic properties, fibrogenicity, irritant effect, etc., depends on its chemical properties. Dust with acidic or alkaline properties is harmful because it causes a change in pH and disrupts the functioning of the epithelium. Dust with allergenic properties (flour, straw, flax, cotton, silk, wool, fruit dust) leads to the development of bronchial asthma (Fig. 11.4).



Fig. 11.4. Dust formation during grain harvesting [5]

When dust particles enter the lungs, they are retained on the surface of the lung tissue, causing them to accumulate and creating a high concentration of toxic substances. Having a large active surface, the particles themselves not only have a negative effect, but also adsorb a large amount of various substances (gases, sols, etc.) on their surface, which also causes the accumulation of toxins and their negative effect on the body. This is especially dangerous in the case of the accumulation of radioactive and carcinogenic substances and heavy metals. There are up to 400 carcinogenic substances, among which the most active and very dangerous are benzopyrene, dibenzanthracene, dioxins, etc. Radiometric

substances, like ionising radiation, inhibit cell division and cause malignant degeneration and mutations.

When dust (especially organic substances) absorbs oxygen, it becomes flammable and can cause an explosion. The explosive hazard of dust depends on its concentration, dispersibility, moisture content, the presence of volatile compounds (especially those with an unpleasant odour), etc. Organic dust is the most dangerous. Dust can cause tuberculosis and anthrax (mild form) in workers involved in the harvesting and processing of wool. Grain dust contains spores of various fungi, including the causative agents of actinomycosis. If the atmosphere is polluted with dust, the lungs are not ventilated properly and become susceptible to various lung diseases. Dust can lead to atrophy and erosion of the mucous membrane of the nose and nasopharynx, catarrh of the bronchi and trachea, exacerbation of pulmonary tuberculosis, and attacks of bronchial asthma.

Air pollution leads to a deterioration in sanitary and hygienic indicators: the frequency of fog increases, visibility and transparency to ultraviolet radiation decrease, the sanitary and living conditions of the population deteriorate, and there is a negative impact on plant growth and the human body. Fog increases the cooling of the body and has a depressing effect on people's mood and well-being. An increase in the amount of dust in the atmosphere reduces its transparency and visibility. Dust and soot penetrate into dwellings, polluting them. The contamination of buildings and houses with ash, soot and resins leads to sulphur compounds destroying building materials and causing metal corrosion.

Atmospheric pollution affects fruit trees, forests, agricultural crops and grass cover. Sulphur dioxide, chlorine, fluorine, dust and resinous substances are particularly dangerous for plants. Poisonous gases have a toxic effect on the protoplasm of plant cells, and sulphur dioxide inhibits photosynthesis. Dust and soot clog the stomata of plant cells, hindering the access of sunlight to chloroplasts. In forests that are polluted by industrial enterprises, bees, birds and animals disappear.

11.4. Pollution standards and environmental quality criteria

To maintain a stable balance in the biosphere, it is necessary to ensure a high quality of the natural environment. The criteria for high quality have been defined:

1) such an environment enables the sustainable existence and development of an ecosystem in a specific location that has historically emerged, been created or transformed by humans;
2) under such conditions, there are currently no adverse effects on any population that is historically or temporarily present in this location, nor are there any threats of such effects in the future.

Air quality is understood as the set of properties of the atmosphere that determine the degree of influence of physical, chemical and biological factors on humans, flora and fauna, as well as on materials, structures and the environment as a whole. Atmospheric pollution is considered to be the direct or indirect introduction of any substance into the atmosphere in such quantities that it affects

the quality and composition of the outside air, causing harm to humans, living and non-living nature, ecosystems, building materials, natural resources – the entire environment. Pollutants are substances of chemical or biological origin that are contained in or enter the atmospheric air and can directly or indirectly adversely affect human health and the environment.

In order to ensure the necessary quality of the natural environment in Ukraine, in accordance with environmental protection legislation, the quality of the natural environment is regulated. The essence of the latter is to establish maximum permissible impact standards that guarantee the ecological safety of the population and the preservation of the gene pool (the totality of all living organisms) and ensure the rational use and restoration of natural resources in the context of sustainable economic development. Accordingly, certain restrictions – maximum conditions (standards) – are imposed on both the impact itself and on environmental factors that reflect the impacts and responses of the ecosystem. Therefore, sanitary-hygienic and environmental standards have been introduced in our country. While sanitary and hygienic standards are based on the principle of "protected people – protected ecosystems," environmental standards take into account the permissible load on the ecosystem. A load is considered acceptable if the deviation from the normal state of the ecosystem does not exceed natural forces and, accordingly, does not cause undesirable consequences for living organisms and does not lead to a deterioration in the quality of the environment. At the current stage of human society's development, the principle of ecological standardisation has limited application (only for some terrestrial plants and aquatic life in fish farming reservoirs).

Ecological and sanitary-hygienic regulation is based on establishing the effects of environmental factors on living organisms, primarily harmful substances and other harmful influences that can lead to negative consequences for both humans and the ecosystem as a whole. The establishment of environmental quality standards is based on the concept of threshold action.

The threshold of harmful action is the minimum dose of a substance that causes changes in the body that go beyond physiological and adaptive reactions, or an undisclosed (temporarily compensated) pathology. Standards limiting harmful effects are established and implemented by specially authorised state bodies in the field of environmental protection and sanitary and epidemiological surveillance.

Sanitary and hygienic standards are based on the establishment of *maximum permissible concentration (MPC)* standards. MPC is the content of harmful substances in a unit of volume (air, water), mass (food products, soil) or surface (workers' skin) which, when exposed for a certain period of time, does not affect human health and does not cause adverse effects in their offspring.

Different types of MPCs are defined for each environment. For the air environment:

- MPC_{wa} – working area, which is considered to be the space up to 2 m above the floor where workers are located (inhalation level);
- MPC_{ms} – maximum single exposure, which should not cause adverse effects in the human body when inhaled for 20 minutes;

- MPC_{ad} – average daily, should not have a negative effect in case of unlimited (over years) inhalation.

For the aquatic environment:

- MPC_W – in water for domestic and cultural purposes;
- MPC_{al} – in the arable soil layer, should not have a negative impact not only on human health, but also on the self-cleaning capacity of the soil.

For food products, MPC_{pr} or the permissible residual amount (PRA) of a substance that does not have a harmful effect on human health has been established.

Table 11.6. Maximum permissible concentrations of harmful substances in the atmospheric air of populated areas

Substance	Maximum permissible concentration, mg/m³		Hazard class
	maximum single	average daily	
Nitrogen oxide (IV) NO_2	0.085	0.085	2
Ammonia NH_3	0.2	0.2	4
Acetone	0.35	0.35	4
Petroleum gasoline (low sulphur)	5	1.5	4
Benzopyrene		0.1 μg/100 m³	1
Butyl alcohol	0.1	0.1	3
Vanadium oxide (V)		0.002	1
Dichloroethane	3	1	2
Methanol	1	0.5	3
Nitrobenzene	0.008	0.008	2
Metallic mercury		0.003	1
Soot (smoke)	0.15	0.05	3
Lead and its compounds in terms of Pb		0.0007	1
Sulphur dioxide SO_2	0.5	0.05	3
Hydrogen sulphide H_2S	0.008	0.008	2
Carbon disulphide	0.03	0.005	2
Hydrocyanic acid HCN		0.01	2
Hydrochloric acid HCl	0.2	0.2	2
Carbon monoxide (II) CO	3	1.0	4
Phenol	0.01	0.01	3
Chromium (CrO_3)	0.0015	0.0015	1
Ethanol	5.0	5	4
Ethylene	3	3	3

The maximum single and average daily MPCs for certain pollutants in the

atmospheric air of populated areas are given in Table 11.6, various types of MPCs in the air for certain substances are given in Table 11.7, MPCs are expressed in milligrams per cubic metre (mg/m^3) in air, in decimetres cubed (mg/dm^3) in water, and in milligrams per kilogram (mg/kg) in soil and food products.Sanitary and hygienic standards mainly take into account the effects of individual pollutants and rarely reflect their combined effects (simultaneous or sequential exposure to several substances) and do not take into account the complex effects of various physical, chemical and biological factors in the natural environment.

Table 11.7. Different types of MPCs in atmospheric air for certain substances

Substance	MPC_{ad}, mg/dm^3	MPC_{Ms}, mg/dm^3	MPC_{wa}, mg/m^3
Nitrogen oxide	0.06	0.4	ZO
Cobalt sulphate	0.0004	0.001	0.005
4-Chloraniline	0.01	0.04	0.3

If there are several pollutants in the air or water, their total harmful effect is taken into account in accordance with the summation effect: the sum of the ratios of the concentrations of individual pollutants to their respective MPCs must not exceed one, i.e.

$$C_1/MPC_1+C_2/MPC_2+ \ldots + C_n/MPC_n \leq 1,$$

where C_1, C_2, ..., C_n are the actual concentrations of the pollutant in the environment (air, water, soil and food products), mg/m^3;

MPC_1, MPC_2, …, MPC_n – corresponding maximum permissible concentrations, mg/m^3.

For substances about which there is insufficient information, temporary permissible concentrations (TPC) and indicative safe exposure levels (ISEL) may be established, and for soils – indicative permissible concentrations (IPC) – these are standards that are calculated and recommended for use for 2–3 years.

Sanitary, hygienic and environmental standards determine the quality of the natural environment in terms of human health and the state of the ecosystem, but do not indicate the source of the impact and do not regulate its activity. The requirements for the sources of impact themselves are reflected in scientific and technical standards: maximum permissible emissions into the atmosphere (MPE) and maximum permissible discharges (MPD) into water bodies, as well as technological, construction, and urban planning norms and rules that contain requirements for the protection of the natural environment.

The *maximum permissible emission into the atmosphere* (MPE) is the amount of harmful substances emitted into the air per unit of time so that the concentration of air pollutants at the boundary of the sanitary zone does not exceed the MPC. MPE is expressed in grams per second (g/s) and tonnes per year. The MDE is established based on the calculation of the dispersion of impurities in the atmosphere.

Quantitatively, the MPE is determined as the product of the dilution coefficient of the pollutant K_P (m^3/s) and the MPC (g/m^3) of this substance contained in gas emissions into the atmosphere:

$$MPE = K_P \bullet MPC,$$

where K_P – is the dilution coefficient, which is equal to the volume of clean air required to dilute the pollutant emitted in one second to a concentration permissible by sanitary MPC standards.

If, for objective reasons, the MPE standards cannot be achieved at an enterprise or group of enterprises located in the same area, then, in agreement with the authorities of the Ministry of Environmental Protection and Natural Resources of Ukraine, a phased reduction of pollutant emissions to values that ensure compliance with the MPE standards shall be introduced. For the period of implementation of measures to ensure compliance with maximum permissible emissions, projects for temporarily agreed emission standards (TAES) and plans for the phased reduction of these emissions to the established MPE standard must be developed and agreed upon for facilities with stationary sources of atmospheric air pollution.

A temporarily agreed emission (TAE) is the maximum amount of pollutants set for an enterprise for the relevant period of achieving the MPE, taking into account the implementation of air protection measures and the level of emissions achieved at enterprises of similar capacity, and during technological processes using the best (in terms of environmental protection) technology for a given production.

MPE and TAE values are set for each source of pollution separately for conditions of full load of technological and gas cleaning equipment and their normal operation. Along with setting MPE and TAE for individual sources, the values of these standards are calculated for enterprises, industrial facilities and complexes as a whole.

The calculation of MPE standards is carried out in accordance with the Methodology for calculating the concentrations of harmful substances contained in industrial emissions in the atmospheric air (OND-86).

The values of MPE and TAE are approved in accordance with the established procedure by the territorial bodies of the Ministry of Environmental Protection and Natural Resources of Ukraine and the bodies of the State Service of Ukraine for Food Safety and Consumer Protection.

They are reviewed in the event of a change in the capacity, production technology or operating mode of an enterprise, or the environmental situation in the region (when new sources of pollution appear or the parameters of existing sources are refined), but at least once every 5 years.

When establishing MPE standards, the main criterion for air quality is the MPC of pollutants in the atmospheric air of populated areas, which must not exceed the established standards at the boundaries and outside the sanitary protection zones of enterprises, i.e.

$$\frac{C}{MPC_{sd}} \leq 1,$$

where C – is the calculated concentration of the pollutant in the surface layer of the atmosphere from all sources.

For substances for which only MPC_{SD} has been established, it is permissible, until MPC_{sd} is established, to use an approximate ratio between the maximum single and average daily concentrations and to comply with the following condition:

$$\frac{0{,}1C}{MPC_{sd}} \leq 1,$$

In the absence of MPC standards, the indicative safe exposure levels (ISEL) shall be used instead, in accordance with the procedure established by the Ministry of Health of Ukraine.

In the presence of certain pollutants with combined harmful effects in the atmosphere, the criterion for determining the MPE is the requirement to comply with the following ratio:

$$\sum_{i=1}^{n} \frac{C_i}{MPC_{sd}} \leq K_{cc},$$

where *i* – is the number of the impurity with combined harmful effects;

K_{cc} – combined effect coefficient – taken from reference tables.

Sanitary protection zones (SPZ) are specially organised areas around enterprises that separate them from residential areas (health resorts, recreation areas, gardening societies, etc.) in order to reduce the harmful effects of these enterprises on human health.

They are located on the leeward side of enterprises and planted with dust-resistant trees and shrubs that have bactericidal properties (birch, white acacia, walnut, oak, Canadian poplar, pine, spruce, elderberry, currant, etc.).

According to the sanitary standards for the design of industrial enterprises, there are five classes of industrial facilities with a sanitary protection zone width, m: class 1A – 3000; 1B – 1000; 2 – 500; 3 – 300; 4 – 100 and 5 – 50. Most food industry production facilities and tank cleaning and washing stations are included in the fifth class with a sanitary protection zone width of 50 m.

The size of the sanitary protection zone is verified by calculating atmospheric pollution in accordance with the requirements, taking into account the prospects for the development of the enterprise and the actual pollution of the atmospheric air.

They are refined for different wind directions depending on the results of calculating atmospheric pollution from the average annual wind rose and the location of the enterprise using the formula

$$L=\frac{L_0 P}{P_0},$$

where L – *is* the calculated size of the sanitary protection zone, m;

L_0 – the calculated size of the area in the direction where the concentration of harmful substances (taking into account the background concentration from other sources) exceeds the MPC, m;

P – *is* the average annual recurrence of wind directions of one compass point in a circular wind rose, % (for example, in the case of a ten-point wind rose, P_0*is* 100/10 = 10%).

If, in accordance with the envisaged technical solutions and calculations of atmospheric pollution, the sizes of the sanitary protection zone for the enterprise exceed the sanitary standards, it is necessary to review the design solutions and ensure compliance with the sanitary standards (reduce the volume of harmful substances emitted into the atmosphere, increase the height of their emissions, etc.). If, after additional review of the solutions, no technical possibilities for ensuring the normative sizes of the sanitary protection zone are found, they are accepted in accordance with the results of atmospheric pollution calculations as agreed by the Ministry of Health and the State Construction Committee of Ukraine. For those areas where the calculated value of L is less than the standard size of the sanitary protection zone, no correction is made and it is accepted as equal to the standard value.

When designing industrial enterprises, certain standards for emissions of harmful substances must be observed, for which the maximum value of the ground-level concentration of the pollutant C_m (mg/m^3) is determined. In the case of harmful gas emissions from a single point source with a circular outlet under unfavourable meteorological conditions at a distance X_m (m) from the source C_m, it is determined by the formula

$$C_m=\frac{AMFmn\eta}{H^2\sqrt[3]{\triangle TV_1}},$$

where A *is* a coefficient that depends on the temperature stratification of the atmosphere (Table 11.8);

Table 11.8. Values of coefficient A

Geographical area	Value of A
Territory of Ukraine	160
For sources located in Ukraine with a height of up to 200 m in the zone from 50° to 52° north latitude.	180
The same south of 52° N.	200

M – mass of harmful substance emitted into the atmosphere, g/s;

F – dimensionless coefficient depending on the settling velocity of harmful substances (for gaseous substances and fine aerosols – dust, ash F = 1. For finely dispersed aerosols with an emission purification coefficient of at least 90%, F =

2; from 75 to 90%, F = 2.5; less than 75% and in the absence of purification, F = 3);

H – height of the emission source above ground level, m;

η – dimensionless coefficient depending on the terrain relief (in the case of flat terrain or with a height difference of no more than 50 m per 1 km g) = 1);

ΔT – difference between the temperature of the emission gases T_2 and the surrounding atmospheric air T_n (the latter is taken as the average maximum air temperature of the hottest month of the year);

min – coefficients;

V_1 – exhaust gas flow rate, m^3 /s.

11.5. Purification of gas and smoke emissions

All possible measures to protect the atmosphere from harmful pollution are shown in Table 11.9. In order to reduce atmospheric pollution by dust and other harmful impurities, it is necessary to consider the possibility of changing raw materials, fuel, technological equipment and its sealing *(infographic 7)*.

Table 11.9. Measures to protect atmospheric air

<table>
<tr><td colspan="4">MEASURES TO PROTECT ATMOSPHERIC AIR</td></tr>
<tr><td>TECHNOLOGICAL MEASURES:</td><td>PLANNING MEASURES:</td><td>SANITARY-TECHNICAL MEASURES:</td><td>LEGISLATIVE MEASURES:</td></tr>
<tr><td>Substitution of harmful source materials with harmless ones</td><td>Zoning of urban areas</td><td>Purification of emissions</td><td>Developments for atmospheric air</td></tr>
<tr><td>Purification of raw materials from harmful impurities</td><td>Organization of sanitary protection zones</td><td rowspan="9"></td><td>Emission standards</td></tr>
<tr><td>Substitution of processing methods</td><td>Proper planning of residential neighborhoods</td><td rowspan="8">Raw material standards</td></tr>
<tr><td>Hermetic sealing of technological processes</td><td rowspan="6">Greening of populated areas</td></tr>
<tr><td>Switching batch processes to continuous ones</td></tr>
<tr><td>Rationalization of combustion processes</td></tr>
<tr><td>Substitution of smoky fuel with smokeless one</td></tr>
<tr><td>Recuperation of harmful emissions and their utilization</td></tr>
</table>

The most common measure to ensure compliance with the standards discussed above is the organisation of effective purification of waste gas emissions. All purification methods can be divided into three groups: mechanical, physical-mechanical and chemical (Tab. 11.10., *infographic 8)*.

Table 11.10. Methods of cleaning waste gas and smoke emissions

<table>
<tr><td colspan="4">Methods of cleaning waste gas and smoke emissions</td></tr>
<tr><td colspan="2">Mechanical</td><td>Physicochemical:</td><td>Chemical:</td></tr>
<tr><td>Dry dust collection:</td><td>Wet dust collection:</td><td>Adsorption</td><td>Chemisorption</td></tr>
<tr><td>Dust settling chambers</td><td>Irrigated apparatuses</td><td rowspan="5">Absorption</td><td>Thermal degradation (Incineration)</td></tr>
<tr><td>Cyclone separators</td><td>Scrubbers</td><td>Thermal oxidation</td></tr>
<tr><td>Mechanical filters (fabric, ceramic, plastic, etc.)</td><td>Bubbling and foam apparatuses</td><td>Catalytic oxidation</td></tr>
<tr><td rowspan="2">Electrostatic precipitators</td><td rowspan="2">Impact-inertial dust collectors</td><td>Catalytic reduction</td></tr>
<tr><td>Catalytic decomposition</td></tr>
</table>

The choice of purification method depends on the amount of waste gases, their composition and physical and chemical properties. Mechanical methods are used to purify ventilation and other gas emissions from coarse dust, in which the dust is separated by gravity, inertia or centrifugal force.

When choosing a dust collection system, it is necessary to consider the gas flow rate, dust content and its physical and chemical properties, particle size and the presence of water vapour. There are two types of dust collection: dry and wet. From an environmental and economic point of view, dry dust collectors are more efficient. They allow the captured dust to be returned to production, whereas wet dust collection produces water suspensions, the processing of which requires greater material costs. The disadvantage of dry dust collection is that it provides a high degree of purification only in the case of low dust content in the waste gases.

Mechanical dry dust collection is carried out in settling chambers, cyclone separators, mechanical and electrical filters. Dust settling chambers clean gases with coarse dust particles ranging from 50 to 500 microns and larger (Fig. 11.5).

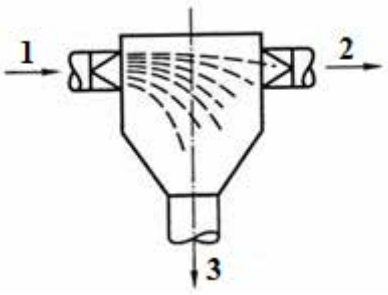


Fig. 11.5. Dust settling chamber
1 – dust-laden gases; 2 – dedusted gases; 3 – dust

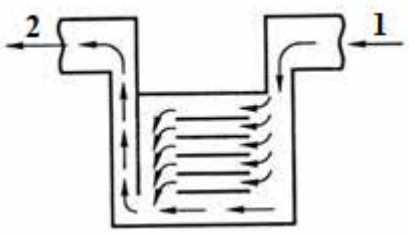


Fig. 11.6. Howard settling chamber
1 – dust-laden gases; 2 – dedusted gases

The Howard settling chamber (Fig. 11.6) is more effective, where the gas flow is broken up into separate sections by horizontal plates. Despite their low aerodynamic resistance and low cost, these devices are rarely used due to the

difficulty of cleaning them. The waste gases from them are sent to other, more efficient devices for further purification.

Cyclone separators (Fig. 11.7) are much more common. In these devices, dust-laden gas rotates in a spiral, throwing dust particles onto the walls of the device 3*, 4,* from where they fall into the dust collection chamber 5. Cyclone separators effectively clean gases containing particles of at least 25 microns in size.

The speed of the exhaust gases is 3 – 45 (usually 12 – 18 m/s). Electricity consumption is 0.035–0.09 kW • h/m^3, maintenance costs are insignificant. The efficiency of cyclones depends on the concentration of dust and the size of its particles. The average efficiency of gas dedusting in cyclones is 78–86% for dust particles 30–40 microns in size. The main disadvantage of cyclones is the significant abrasive wear of the device parts by dust. Therefore, these parts are coated with synthetic or wear-resistant alloys, which increases the cost of the device. Cyclones are used to clean dusty gases and air with large particles in various industries.

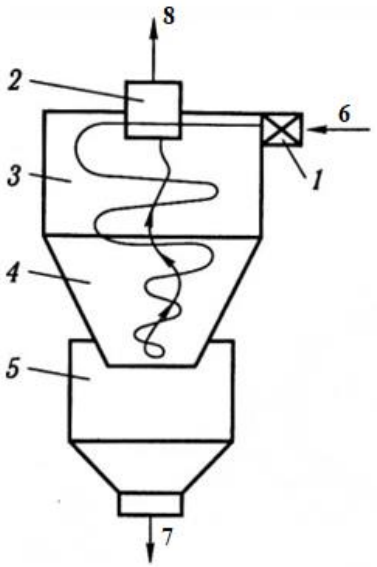


Fig. 11.7. Cyclone:
1 – inlet pipe; 2 – exhaust pipe; 3 – cylindrical chamber; 4 – conical chamber; 5 – dust settling chamber; 6 – dust-laden gas; 7 – dust; 8 – cleaned gas

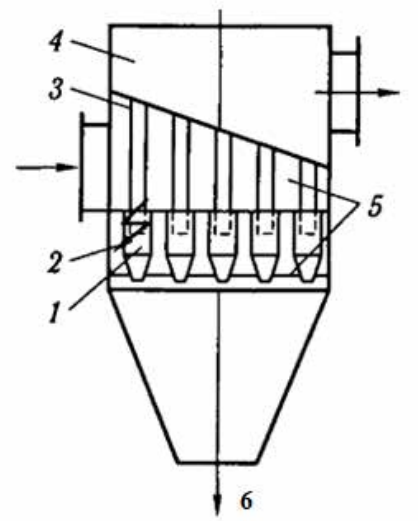


Fig. 11.8. Battery cyclone:
1 – ring slot; 2 – guide device for swirling gases; 3 – distribution chamber; 4 – purified gas chamber; 5 – support grate; 6 – dust

More efficient devices, but much more complex in design, are battery cyclones (Fig. 11.8). They consist of a large number of cyclone elements installed in parallel, combined in a single housing with a common gas inlet and outlet, and a collection hopper. More than 20 different types of cyclones are widely used in Ukraine.

The efficiency of cleaning dusty gas flows, especially those with highly dispersed dust, is significantly increased when waste gases are filtered through porous partitions or other filter materials. In filters, the gas flow passes through porous material of varying density and thickness. Coarse dust is cleaned in filters

filled with coke, sand, gravel, and nozzles of various types and shapes. Paper, felt or fabric of various densities are used as filter materials for cleaning fine dust. Paper is used to clean atmospheric air or gases with low dust content. In industrial conditions, fabric or bag filters are used, which are shaped like drums, fabric bags or pockets working in parallel.

Multi-section bag filter: the linear filtration speed depends on the nature of the dust, the concentration and size of the particles, the temperature and the composition of the gas. The pressure of the compressed air used for blowing is 4.2–5.6 MPa, and the flow rate is about 0.0025 cm^3/s per 1 m^2 of surface area. Electricity consumption is 0.0254–0.09 kW • h/m^3 (Fig. 11.9).

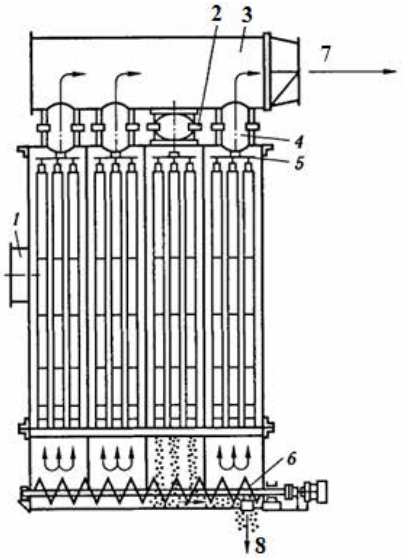


Fig. 11.9. Multi-section bag filter:
1 – inlet duct; 2 – shaking mechanism during regeneration; 3 – outlet duct; 4 – section valve; 5 – frame for suspending the bags; 6 – electrically driven screw conveyor for dust removal; 7 – cleaned gas; 8 – dust

Each section has several sleeves. Dusty gas enters the sleeve from the bottom of the section. Passing through the fabric, it is cleaned and exits through an open exhaust valve into the exhaust gas duct. Dust settles on the inner surface of the sleeves. When the dust layer reaches a certain thickness, the gas supply is stopped. The dust is removed to the hopper by a shaking mechanism. In the case of reverse blowing, clean air is directed through the blow-off valve. At the same time, the outlet valve closes automatically. Filters usually operate at pressures up to 2.5 kPa, G 4 – 5 FM filters – up to 20 kPa, and FRU, FVS – 45 and FRN – 30 filters – at pressures of 30, 60, 80 kPa, respectively.

Recently, synthetic materials and glass fibre have been widely used as filter fabrics, which can withstand temperatures of 150–250°^{0}C. They are more chemically and mechanically resistant and less moisture-absorbent than wool and cotton. The latter allow gases with a temperature not exceeding 100°^{0}C to be cleaned. The main advantage of bag filters is their high cleaning efficiency, which reaches 99% for all particle sizes. Ceramic filters, plastic or glass filters are used for fine cleaning. Their dust collection efficiency can reach 99.99%, and the temperature of the purified gas can reach 500°^{0}C.

Electrostatic precipitators are used for fine cleaning of gases from dust. In addition to dust, they can also clean gases from aerosols and hydrosols, i.e. capture more dispersed particles. An electrostatic precipitator consists of a precipitation (positive) electrode 1 and a corona (negative) electrode 2. The precipitation electrode is made in the form of a tube or plate. The electrostatic precipitator is powered by high-voltage direct current (50–100 kV).

At an electric field strength of 15 kV/cm between the electrodes, the air is ionised and creates positive and negative charges. The charged particles settle on the dust particles, causing them to move towards the oppositely charged electrodes and settle on them. In dry electrostatic precipitators, 5 impact hammer-type shaking devices are used to clean the electrode surface from dust. The hydraulic resistance of electrostatic precipitators does not exceed 100–150 Pa. Electrostatic precipitators are used to clean large volumes of gases from dust with particle sizes of 0.01–100 μm at gas temperatures up to 500°^{0}C. The filters work effectively with low gas flows, achieving a purification degree of 99.9%.

The disadvantages of electrostatic precipitators include high metal content and bulkiness, high sensitivity to deviations from the set operating modes, and high requirements for dust explosion and fire safety. Due to high capital costs, it is economically feasible to use electrostatic precipitators for large gas consumption (there are filters with gas consumption of more than 1 million m³/day).

Electrostatic precipitators are divided into single-zone (dust particles are charged and deposited in one zone) and dual-zone (the same processes occur in different zones – in the ioniser and in the precipitator). Two-zone filters are used to clean gases with a lower dust content, since the distance and voltage between the electrodes is lower than in single-zone electrostatic precipitators. Depending on the direction of gas flow, electrostatic precipitators can be horizontal or vertical. Multi-field (several electric fields) horizontal electrostatic precipitators, in which the parameters of each electric field can be adjusted, are widely used. Vertical electrostatic precipitators are single-field and dual-field. Wet vertical electrostatic precipitators are used more often than dry vertical ones.

To increase dust collection efficiency, cleaning devices are sprayed with water. In wet dust collectors, dusty gas is sprayed with liquid or comes into contact with it. The simplest design is a washing tower, filled with Raschig rings, glass fibre or other materials. Scrubbers and Venturi pipes belong to this type of equipment. Venturi pipes are often supplemented with cyclones to remove the sludge that forms. A hollow nozzle scrubber is a cylindrical (or rectangular) tower made of metal, brick or reinforced concrete. Scrubbers operate on the counterflow principle: the gas moves from bottom to top, and the absorbent liquid (usually water) is sprayed from top to bottom through nozzles.

The gas velocity in scrubbers is 1.0–1.5 m/s. The efficiency of gas cleaning depends on the wettability of the dust and reaches 96–98%. Water consumption is 0.157–1.57 l/m^3, electricity consumption is 0.035–0.35 kW h/m^3. To capture dust that is difficult to wet, such as coal dust, a surfactant (surfactant) is added to the water. Scrubbers are used for cold and hot gases that do not contain toxic

substances (acids, chlorine, etc.), as they are released into the atmosphere together with the purified gas in the form of mist.

In bubble scrubbers, dusty gas is passed through a liquid (water). They are suitable for cleaning hot gases with dust particles larger than 5 microns. Bubble scrubbing is also used in foam scrubbers. Surfactants are added to the water to create foam. The cleaning efficiency in these scrubbers reaches 97–99%.

The disadvantage of wet gas cleaning is that the captured dust turns into wet sludge. To remove the latter, it is necessary to build a sludge sewer system, which increases the cost of construction. Wet dust collectors of the Venturi tube type are characterised by significant energy consumption for water supply and spraying, especially for capturing dust with particle sizes less than 5 μm. During the purification of some gases, alkaline or acid corrosion is possible. The dispersion conditions are significantly worsened by factory pipes for waste gases, which are moistened during cooling in devices of this type.

In inertial dust collectors, the direction of the flow changes sharply. Dust particles strike the surface by inertia, settle and are removed from the device through a discharge device. Plates or rings are placed inside the device, which the gas hits. The devices can be sprayed with water from above. Then the dust is removed from them in the form of sludge.

Ultrasonic devices are used to increase the efficiency of cyclones or bag filters. Ultrasound promotes the adhesion and fixation of dust particles. These devices are effective in cases of high dust concentration in the gas being cleaned. To increase the efficiency of the device, it is sprayed with water. Such devices, in combination with a cyclone, are used to capture soot, mist of various acids, etc.

Absorption and adsorption are among the physical and chemical methods of gas emission purification.

Absorption is the process of chemical precipitation or binding of pollutants during the passage of gas, which is purified through a liquid absorbent. The physical essence of the absorption process is explained by the film theory, according to which liquid and gaseous films are formed at the interface between liquid and gaseous substances when they come into contact. The gas-air mixture impurity dissolved in the liquid penetrates by diffusion first through the gas film, then through the liquid film, and enters the inner layers of the absorbent. For diffusion to occur, the concentration of the dissolved impurity in the gas-air mixture must be greater than its equilibrium concentration in the liquid. The less saturated the solution, the more gas it can absorb.

The absorbent is selected based on the solubility of the absorbed gas in it, the temperature and the partial pressure. The absorption process is selective and reversible. This means that it is possible to select an absorbent that will absorb only certain impurities that need to be removed from the gas being purified. The removed impurities can be desorbed from the absorbent by one method or another. The absorbent is returned to the process for reuse.

The devices in which absorption takes place are called absorbers. Absorption is used to remove the vapour phase, non-condensable emissions and odours. In these devices, the gas being purified and the absorbent liquid move towards each

other.

Schematic diagram of a plant for the absorption-desorption removal of pollutants from gases: the contaminated gas enters the absorber, where the gas pollutant to be removed comes into contact with the cold absorbent. The latter selectively absorbs the pollutant. The purified gas is released into the air. The absorbent solution containing the absorbed pollutant enters the heat exchanger, is heated in it and fed by a pump into the desorber. The absorbed pollutant is desorbed by heating the absorbent with steam.

The purified absorbent returns to the absorber through the heat exchanger and refrigerator, thus performing multiple circulations. Absorption is used to purify air and waste gases containing toxic substances – acid mists, carbon (IV) and (II) oxides, cyanide or acetic acids, sulphur dioxide, nitrogen oxides, various solvents, etc. Suspensions containing magnesium and calcium oxides or limestone are used as absorbents:

$$2CaO + 4NO_2 + O_2 \rightarrow 2Ca(NO_{32}); \; CaO + CO_2 \rightarrow CaCO_3;$$

$$MgO + SO_2 \rightarrow MgSO_3;$$

$$CaO + SO_2 \rightarrow CaSO_3;$$

$$CaCO_3 + 2HC1 \rightarrow CaCl_2 + H_2O + CO_2\uparrow.$$

Water, alkali and carbonate solutions, ammonia water, etc. are most commonly used as absorbents.

The purification efficiency is 90–95%. After purification, the sludge can be used for further processing and product extraction. The disadvantage of these devices is the complication of the sludge removal process in the case of the formation of poorly soluble substances. Purified gases are released into the atmosphere, if sanitary requirements allow.

Absorbers of various designs are used: film, nozzle, tubular, etc. The most common universal absorber is a tower with a nozzle, where the absorbent moves from top to bottom and the gas flow moves from bottom to top. The advantage of these devices is their simple design, reliability and stability of the process, while the disadvantage is their relatively low productivity and large volume: water consumption is 0.0037–0.037 l/m^3.

To clean yeast-growing air emissions containing microdroplet aerosol of the nutrient medium with yeast cells, a biological method of absorption cleaning is used at the yeast plant.

The basic design of the biofilter is shown in Figure 11.10. The apparatus contains horizontal wooden grates coated with a layer of biologically active material (mainly a mixture of straw, sawdust and fine shavings) with a consortium of non-pathogenic microorganisms immobilised on it. Air emissions under excess pressure are fed through an air duct into the biofilter under the wooden grating, where they pass through a layer of biologically active filter material.

Drops of microbial aerosol settle on the surface of the material and flow down to the bottom in the form of liquid, after which they are removed through a

drainage drain. The purified air is discharged into the atmosphere through a gap between the fence and the ceiling. A biofilter with an area of 20 m² purifies almost completely 7000 m³/h of emissions from unpleasant-smelling substances. The concentration of yeast cells in air emissions decreased from 1.5–2.5 million cells/m³ before filtration to 600–1,500 cells/m³ after filtration (with an approximate safe level of 5,000 cells/m³).

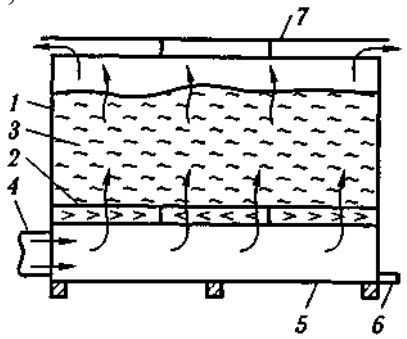


Fig. 11.10. Biofilter:
1 – sealed vertical enclosure; 2 – wooden horizontal support grates; 3 – biologically active filter material; 4 – air supply pipe; 5 – bottom; 6 – drainage pipe; 7 – ceiling

The biofilter, located on the roof of the workshop, worked satisfactorily even in winter conditions (at a temperature of –30°C). Long-term operation of the biofilter (throughout the year) confirmed its reliable and effective performance. It achieved almost complete purification of emissions from yeast cells and substances with an unpleasant odour without compromising the quality of seed and commercial yeast. Biofilters are simple in design, reliable and economical to operate, and do not require operating costs. They can be used to deodorise air emissions from any food industry enterprise.

The adsorption method of gas purification is the sorption of gaseous substances on the surface or in the volume of the micropores of a solid body. A solid substance on the surface or in the volume of the pores of which the purified substances are concentrated is called *an adsorbent.* In technology, solid adsorbents with a highly developed internal surface are used. Most often, activated carbon, silica gel and clays with a large surface area are used as adsorbents. One gram of activated carbon has a surface area of about 5 km². The substances removed from the purified gases – adsorbates, which are subsequently separated by desorption – can be used for various purposes. This process is called adsorbent regeneration and is usually carried out by heating with superheated steam. The devices in which adsorption takes place are called adsorbers. They are made vertical, horizontal and with ring shelves on which the adsorbent is placed. Activated carbon comes in granular and powdered forms, depending on the size and shape of the particles. Granular carbon is manufactured in the form of cylinders with a diameter of 2 to 5 mm, with the height of the cylinder always greater than the diameter. Granular carbon is mainly used in installations with a stationary adsorbent layer.

To increase the surface area and intensity of mass transfer, granular carbon is crushed and dispersed into fractions. Crushed carbon is used in processes with a stationary, moving and boiling layer of adsorbent. In this case, the process is carried out in a continuous mode using carbon granules with increased abrasion

resistance. The advantages of the continuous process are its full automation, the possibility of performing chromatographic separation of the mixture of components along with their separation from the gas, and a reduction in heat consumption for coal regeneration. The disadvantages of the method include high energy consumption due to the high resistance of the adsorbent layer. The velocity of the purified gas is usually less than 0.5 m/s, the gas temperature is below 303 K, and the relative humidity is less than 100%. The amount of substance adsorbed by coal is 1 – 40 % of the mass of coal in a saturated state; during recirculation, it is 1 – 20 % by mass, and the efficiency of contaminant removal is 85 – 99 %.

Adsorption on activated carbon is used to purify waste gases from hydrogen sulphide, and on silica gel – gas emissions from nitrogen oxides. This method is widely used to purify waste gases from many other harmful impurities with an unpleasant odour.

Chemical methods of waste gas purification are based on the chemical binding of harmful pollutants. A very common method is chemisorption, when the gas to be purified is washed with a solution of substances that react with the polluting impurities. For example, peat-ash compositions with calcium hydroxide or ammonia are used to capture nitrogen oxides. Chemosorption produces a fertiliser with 6–8% bound nitrogen in the form of calcium and ammonium nitrates.

Incineration is used to neutralise combustible hydrocarbons that are not used in production. From an economic point of view, this is an inefficient process, since the heat is not used and only leads to thermal pollution of the environment. If the concentration of combustible substances is insufficient for combustion, *thermal oxidation* is used. In this case, the gas to be purified is burned in a burner flame.

In many cases, catalytic oxidation, reduction and decomposition processes are used to neutralise waste gases. For example, automobile exhaust gases are purified of carbon monoxide (II) by oxidation to carbon dioxide on a copper-manganese catalyst, which is a mixture of manganese and copper oxides:

$$2CO + O_2 \rightarrow \mathbf{2CO_2}$$

Catalytic reduction of nitrogen oxides to N_2 is carried out using reducing agents – hydrogen, methane or ammonia in the presence of platinum-palladium-rhodium catalysts.

Questions for discussion and self-assessment

1. Describe the sources of atmospheric air pollution at food enterprises.
2. Name the sources of dust pollution in the atmosphere at food enterprises.
3. What are the criteria for classifying industrial air pollution?
4. Using examples from food enterprises, explain what organised and unorganised, primary and secondary emissions are.
5. How are sources of atmospheric air pollution classified according to industrial emissions?
6. How is pollution classified according to the degree of danger?

7. Describe the following atmospheric pollutants: SO_2, H_2O, CO, N_xO_y.
8. What happens to nitrogen oxides and sulphur oxides that enter the atmosphere with gas emissions?
9. How does atmospheric air pollution affect the environment and human health?
10. Name the criteria for atmospheric air quality and define them.
11. What is the threshold of harmful effects?
12. What is the basis for sanitary and hygienic standards?
13. In what cases are temporarily permissible concentrations of pollution established?
14. Define the maximum permissible emission into the atmosphere. How is it calculated?
15. What is a temporarily agreed emission (TAE) and in what cases is it applied?

CHAPTER 12. PURIFICATION AND DISPOSAL OF SMOKE EMISSIONS FROM SMOKING CHAMBERS

Smoke emissions from smoking chambers are not highly potent air pollutants. However, the environment needs to be protected from these emissions, as smoking smoke contains almost all groups of organic compounds.

According to the Law of Ukraine on Environmental Protection, smoke emissions from smoking installations must either not contain harmful substances in quantities exceeding the legally permissible limits or must be neutralised to the required level.

12.1. Chemical composition and physical parameters of smoke emissions from smoking chambers

Smoke from smoking is a complex multi-component system of vapour, liquid and solid substances that are products of the thermal decomposition of wood. The composition of smoke from smoking depends on the type, size and moisture content of the wood, the method of smoke production, the temperature of smoke formation and other factors.

Pyrolysis of different types of wood at 400°^{0}C results in the formation of approximately 45–50% liquid distillate, 32–38% charcoal and 15–20% gases from the mass of absolutely dry wood. The amount of precipitated and soluble resin in coniferous and deciduous wood varies, while the yield of charcoal, non-condensed gases and water is approximately the same. The soluble resin of coniferous and deciduous species consists mainly of levoglucosans, volatile acids and organic residue. The proportion of soluble resin is about 50%, while the other half – sedimentary resin – contains about 60% phenolic substances, 36% neutral substances and 10% acids. Alcohols and carbonyl compounds predominate in neutral compounds (from 45 to 70%).

Smoke from smoking contains various inorganic compounds: sulphur dioxide, nitrogen dioxide, carbon monoxide and ammonia. Smoke contains more than 1,000 individual organic compounds belonging to such classes of chemical compounds as phenols, acids, carbonyl compounds, alcohols, esters, amines, polycyclic aromatic hydrocarbons (PAHs), etc. Smoke also contains many compounds that are harmful to human health and have a cumulative effect, but they are present in small quantities.

When smoking fish, up to 95% of the smoke is released into the atmosphere, polluting it, and many components of the smoke are present in virtually the same quantities as in the original smoke. It is known that smoke emissions from hot smoking chambers are more saturated with organic compounds than emissions from cold smoking chambers.

In physical terms, smoke is a condensation-type aerosol formed by the incomplete combustion of carbon-based organic substances wood. The dispersed medium of smoke consists of 70–90% non-condensed gases – CO and CO_2, which

are components of air, with water accounting for 9–19%, as well as organic compounds in a vapour state. The dispersed phase of smoke consists mainly of the same organic compounds as the dispersed medium.

The distribution of smoke components between the dispersed medium and the dispersed phase depends on the temperature of the smoke-air mixture, as well as the boiling point of the initial organic compounds. Low-boiling components such as methyl alcohol, formaldehyde, formic acid, etc. are mainly concentrated in the dispersed medium.

Smoke is an aerosol system of medium dispersion with an average particle radius of 0.1 to 3.5 micrometres, with the relative proportion of particles with a radius of 0.1 to 0.75 micrometres, regardless of the method of smoke production, being 85 to 87%.

Knowledge of the dispersed composition of smoke, the patterns of distribution and changes in particle size during the smoking process contributes to the informed choice of a method for cleaning smoke emissions from smoking chambers.

Since it is difficult to identify individual compounds in smoke emissions and the composition of smoke varies significantly, the content of organically bound carbon (total carbon) is used as a measure of emissions from smoking installations, and the carbon content in purified smoke should not exceed 50 mg/m^3.

12.2. Methods and equipment for cleaning smoke emissions from smoking chambers

In fish processing enterprises, in order to protect the air environment from smoke emissions from smoking production, they are purified using various technological installations that selectively capture solid, liquid or gaseous harmful substances. Solid and liquid impurities are captured by cyclones, filters with ceramic, porcelain-ceramic rings, and Raschig rings. Physical and chemical methods (adsorption, absorption, chemisorption) are used to remove gaseous impurities. Gravity (dust settling chambers), inertial and other dust collectors are used in industrial purification plants.

Water inertia purification method

This method combines the inertial effect with a wet cleaning method. The flow of smoke from the smokehouse through the central pipe is fed into the cleaning chamber, where the smoke hits the water surface and creates a wave as a result of the displacement of water from under the end of the tube. The wave hits the wall, returns, collides with a new incoming wave, resulting in the creation of a turbulent zone and the formation of a smoke-water mixture. At the same time, the smoke bubbles through the water (Fig.12.1).

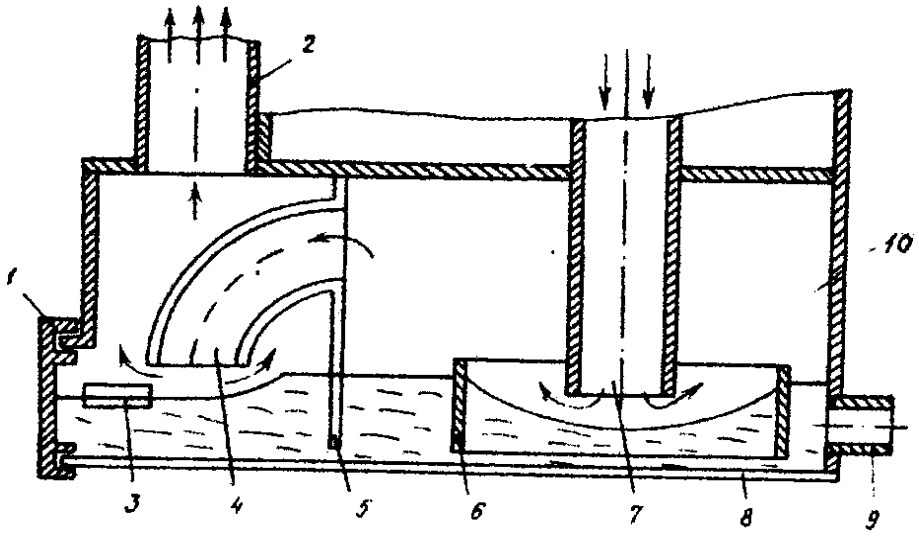


Fig. 12.1. Water-inertial method for cleaning flue gas emissions from smoking chambers
1 – cover; 2 – exhaust pipe; 3 – water drain tray; 4 – elbow; 5 – partition; 6 – baffle; 7 – flue pipe; 8 – housing; 9 – water pipe; 10 – cleaning chamber

When the smoke comes into contact with water, ash and tar particles are trapped by the water due to their inertia and gravitational settling. The water carries away some of the contaminants in the flow and is discharged via chute 3, whilst the tar settles at the bottom of the unit and is periodically removed. The smoke then passes through a labyrinth formed by partition 5 and elbow 4, strikes the water surface again, and is discharged into the atmosphere via pipe 2.

Thermal decontamination

The thermal method of decontamination is based on the oxidation of organic compounds with oxygen at high temperatures. Depending on the conditions of the oxidation regime and the composition of the waste, the thermal method is divided into a number of methods:

- fire disposal;
- thermal oxidation;
- catalytic afterburning.

Incineration

The process of incineration of flue gas emissions is usually carried out directly in a flame at a temperature of 800–1500 ^{0}C. The flue gas incineration plant consists of a waste reception and feeding unit, a device for feeding waste into the furnace and distributing it therein, and a flue gas cleaning system. The completeness of incineration is influenced by the temperature, the specific load of the working volume of the furnace, the excess air coefficient, etc (Fig. 12.2).

The spent smoke is directed by exhaust ventilation to the resin pre-separation tank, which is achieved by a lower temperature in the chamber and tangential supply of the smoke-air mixture. Then, with the help of a fan, it is directed through the chimney into the air duct of the gas-oil burner installed in the boiler furnace, where it is neutralised. The smoke duct also serves as a resin condenser and is installed with a slope towards the resin collector, where the resin is periodically

heated by a coil to reduce its viscosity, and then fed by a fuel oil pump into the liquid path of the gas-oil burner for combustion.

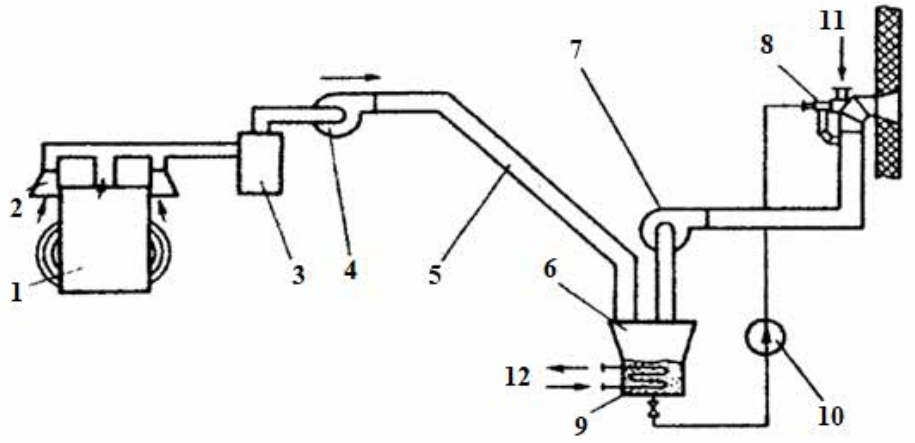


Fig. 12.2. Schematic diagram of the thermal treatment system for gases from fish smoking operations in boiler furnaces

1 – smoking oven; 2 – exhaust ventilation system; 3 – resin pre-separation tank; 4 – fan; 5 – flue; 6 – resin collector; 7 – fan; 8 – air duct of the gas-oil burner; 9 – coil for periodic heating of separated resin and reduction of its viscosity; 10 – oil pump; 11 – gas; 12 – vapor

The fuel in the thermal disposal unit is usually gas or fuel oil, the combustion of which produces highly toxic compounds, the concentration of which in the purified emissions can exceed the permissible limits many times over. For example, prolonged exposure of gas to high temperatures and excess air leads to the formation of nitrogen oxides.

When used as fuel oil, the sulphur it contains forms sulphur dioxide, the amount of which may exceed the amount of carbon burned. As a result, by eliminating pollutants of one type, the process of thermal destruction becomes a source of pollutants of another type, so thermal destruction is only used when the waste gases provide a significant part of the energy required for the process. For economic reasons, this share should not exceed 50% of the total heat of combustion. It is necessary to monitor the completeness of gas combustion, since incomplete combustion converts alcohols into odorous carbonyl compounds.

With complete combustion, there is no odour in the exhaust gases. Due to fuel shortages, this method of disposal is used extremely rarely.

Thermal oxidation

Thermal oxidation is used at low concentrations of combustible impurities, which provide only a small fraction of the heat required to maintain the flame.

With this method of disposal, the flue gas stream is usually heated in heat exchangers and then passes through the working zone of the burner, into which fuel is additionally introduced. The components of the flue gas are heated to temperatures that cause them to self-ignite and are burned by oxygen introduced by a blower or fan. The main advantage of this method is that thermal oxidation is carried out at relatively low temperatures (500–800 ^{0}C), which reduces the cost of manufacturing the combustion chamber and avoids significant formation of

nitrogen oxides.

For complete combustion of smoke components, 0.2–0.8 seconds is usually sufficient. The degree of turbulence in the smoke flow significantly affects the efficiency of oxygen contact with fuel and combustion products and plays an important role in the neutralisation of potent compounds. Increased flow turbulence is achieved through proper design of the burner and underwater chimney at minimum operating temperature.

Catalytic method

This method of smoke emission neutralisation involves oxidation-reduction processes at a temperature of 100–500 ^{0}C on the surface of the catalyst. The catalyst accelerates oxidation to a few hundredths of a second without undergoing chemical transformations. The effectiveness of neutralisation is significantly influenced by the initial smoke concentration, temperature, contact time and catalyst quality. Platinum, palladium, nickel, zinc, copper and other metals applied to a carrier, such as aluminium oxide, are used as catalysts (Fig. 12.3).

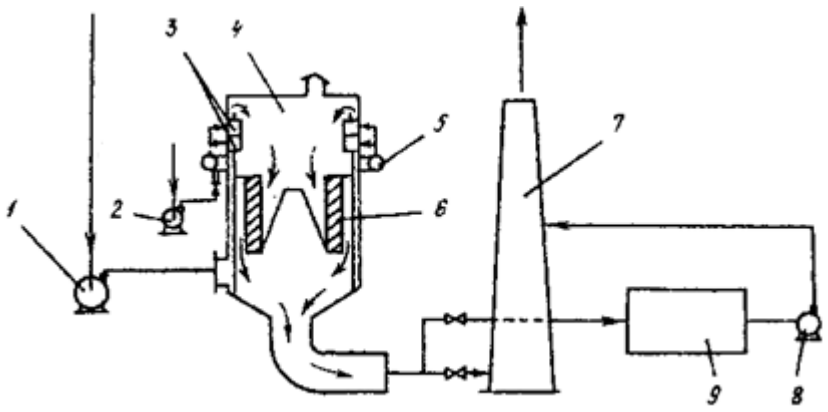


Fig. 12.3. Installation of catalytic after-treatment for flue gas emissions
1 – flue gas fan; 2 – air supply fan; 3 – burners; 4 – reactor; 5 – air manifold; 6 – catalyst basket; 7 – flue; 8 – flue gas extractor; 9 – waste heat boiler

The M-2 catalyst is often used, which is an e of applying an active film containing thousandths of platinum to a chromium-nickel spiral. When using such a catalyst, complete neutralisation of all toxic compounds in the smoke emissions from cold smoking chambers is achieved at a temperature of 350°^{0}C and a volumetric flow rate of 2000 m^3/hour. To achieve complete purification of smoke emissions from hot smoking ovens using the same catalyst, a temperature of 500°^{0}C and a volume flow rate of 1500 m^3/h are required.

It is known that the catalytic activity of catalysts for different organic compounds varies. Therefore, 100% purification of carcinogenic and toxic components of smoke emissions is impossible. In addition to polycyclic aromatic compounds (such as 3,4-benzopyrene), flue gas emissions released into the atmosphere also contain other classes of organic compounds with different properties and, therefore, different catalytic activity.

Catalytic oxidation ensures the removal of foul-smelling (strongly odorous) smoke emissions. In catalytic destruction units, the degree of combustion is usually 75–97%, so that the gases from this process consist mainly of carbon dioxide, steam and nitrogen.

The disadvantages of the catalytic method of neutralisation include a reduction in the service life of catalysts due to poisoning, inactivation of the catalyst surface due to carbon deposits, or a reduction in the catalyst surface area due to abrasion by smoke particles in the gas flow. To extend the service life of catalysts, smoke emissions must be thoroughly cleaned (filtered) of solid particles before entering the plant, as these particles reduce the surface area of the catalyst available for the catalytic reaction.

12.3. Electrostatic precipitation

A distinctive feature of electrical cleaning is the targeted use of all the energy of the process to move smoke particles, whereas in other cleaning methods, energy is transferred to the entire smoke flow.

The installation is powered by high-voltage rectified current, which is obtained from electrical units consisting of a voltage regulator, a step-up transformer that converts 380/220 V alternating current into 100 kV direct current, and a high-voltage rectifier 3 (Fig. 12.4).

After the rectifier, the current is supplied to the electrodes and the electrostatic precipitator. The body of the electrostatic precipitator usually has a rectangular or cylindrical shape and is made of materials resistant to the chemical and mechanical effects of smoke emissions (steel, brick, reinforced concrete). Thus, purification is carried out in a system consisting of a grounded (precipitating) electrode and a corona electrode. High-voltage current is supplied to the latter, and ions are formed on its surface, which, under the action of electric field forces, move in the direction of the precipitating electrode, and an electric current arises in the interelectrode space.

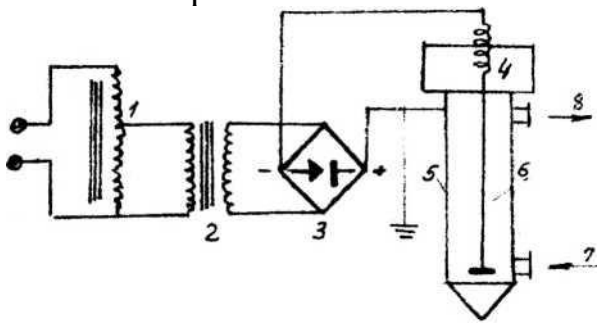


Fig. 12.4. Schematic diagram of a flue gas electrostatic precipitator
1 – voltage regulator; 2 – step-up transformer; 3 – high-voltage rectifier; 4 – corona electrode; 5 – separation electrode; 6 – electrostatic precipitator; 7 – flue gas inlet; 8 – purified gas outlet

The essence of the process of electrical cleaning of flue gas emissions is the ionisation of smoke particles and their precipitation on the oppositely charged precipitation electrode. The speed of particle movement depends on the electrical friction forces that arise when the particles move towards the precipitation

electrode perpendicular to the main gas flow.

In the electrical cleaning method, the dispersion composition of flue gas emissions is of great importance, since the number of collisions between ions and smoke particles is proportional to the radius of the latter. The maximum electric charge obtained by a smoke particle with a radius greater than 1 μm is proportional to the square of the particle radius, and for a particle with a radius less than 1 μm, it is proportional to the particle radius. Therefore, large particles obtain an electric charge faster and are the first to settle on the precipitator.

When using electrostatic precipitation, the organic carbon content in flue gas emissions is reduced from 1400 to 500 mg/m^3 with an electricity consumption of about 1 kW. The low degree of purification is due to the fact that the bulk of the flue gas emissions (about 90%) consist of particles with a radius of 0.1–0.75 μm, and the ions generated on the high-voltage electrode are poorly adsorbed on the finely dispersed smoke particles, pass through the precipitation zone and are emitted into the atmosphere.

In addition, smoke components in a droplet-liquid state in the form of resins flow down under the action of gravity when deposited on the precipitation electrode. They form an uneven layer of resin on the surface of the electrode, which leads to deviations from the specified electro-cleaning modes. To increase the efficiency of this cleaning method, it is used in combination with a wet scrubber, known as a «wet electrostatic precipitator».

Smoke emissions, passing through a system of spray nozzles in the pre-treatment chamber, are partially condensed and enlarged. They then enter an electric precipitator, in which the precipitation electrode is covered with a water film and is self-cleaning, as the dispersed smoke particles that settle on it are immediately removed along with the water.

The capacity of the installation is 220 m^3/min with a water consumption of 23 dm^3/min. Operation of the installation ensures the removal of up to 99.9% of particles smaller than 10 km and 100% of particles larger than 10 μm from the emissions of the smoking chambers.

Given the high rate of smoke component capture in electrostatic precipitators, a method was developed and a device was manufactured for obtaining smoke liquid using high-voltage electrostatic fields.

The essence of the method: smoke enters the ionisation chamber, where soot separation and selective precipitation of the largest resins occur, and the remaining smoke particles become charged. This allows for more complete capture of smoke components in the precipitation chamber, where finely dispersed water is introduced through a nozzle connected to the negative pole of a high-voltage source.

The aqueous solution saturated with smoke components flows into a receiver, from where it can be fed back into the precipitation chamber to increase the concentration of smoke components. After saturation to a certain concentration, the aqueous smoke solution is settled, filtered and used as a smoking liquid.

The disadvantages of electro-purification include the high sensitivity of the

purification process to deviations from the specified technological mode, significant capital costs for the construction of installations, the complexity of electrical equipment, and the inability to remove harmful substances found in a dispersed medium.

12.4. Adsorption

Adsorption, or dry purification, is based on the absorption of various components by a solid substance (adsorbent). The adsorption rate depends on the concentration, nature and structure of the captured compounds, the temperature and pH of the medium, and the type and properties of the adsorbent. To intensify the adsorption processes, it is necessary to use a fluidised bed of adsorbent. In general, the adsorption process consists of the transfer of compounds to the surface of the adsorbent, the adsorption itself, and the transfer of compounds into the adsorbent grain.

After repeated use, the adsorbent is regenerated. Air, inert gases, saturated and superheated water vapour are used as desorbing agents. To remove organic substances from the surface of the adsorbent, either displacement desorption is used, or the adsorbent is subjected to calcination. In the practice of smoking production, activated carbon, sodium carbonate, calcium hydroxide, lime, etc. are used for adsorption purification of smoke emissions.

In industry, continuously operating multi-chamber fluidised bed adsorbers are commonly used.

In a single-chamber fluidised bed adsorber, the gas continuously moves through the body from bottom to top, keeping the adsorbent layer on the gas distribution grids in a fluidised state.

The gas is removed from the apparatus through a cyclone device, which serves to separate the small particles of adsorbent trapped in the gas. In these devices, which operate on the principle of countercurrent phases, it is only possible to achieve an equilibrium concentration of adsorbent in the gas phase, which corresponds to the average concentration in the layer.

In a multi-chamber adsorber with a boiling layer, the gas sequentially passes through perforated plates (gas distribution grids) with overflow pipes, through which solid adsorbent particles "flow" from stage to stage in countercurrent to the gas. With a fluidised adsorbent, at each stage of interaction, the gas approaches the ideal mixing mode, while for the apparatus as a whole, this interaction is close to the ideal displacement mode. Under such conditions, the gas is evenly distributed over the cross-sectional area of the apparatus, the interaction time of the phases increases, thereby achieving a more complete utilisation of the adsorbent's absorption properties.

During the adsorption process in the boiling layer, the adsorbent is subjected to increased abrasion, therefore, when selecting an adsorbent, its mechanical strength should be taken into account.

The most interesting method of flue gas purification is as follows: an aqueous solution or aqueous suspension of the adsorbent is pumped to a centrifugal

distributor installed in the upper part of the working chamber. The adsorbent is sprayed in the form of finely dispersed droplets and mixed with the flue gas entering the chamber. As a result of the interaction, water evaporates from the adsorbent and a dry residue is formed, which is collected and removed for further processing. Such installations can remove up to 90% of impurities from smoke.

Adsorption can be used to remove malodorous substances from the smoke stream, but the high cost of adsorption purification prevents this method from being widely used in smoking production for the neutralisation of smoke emissions.

12.5 Absorption

The absorption purification method consists of contacting the smoke stream with an absorbent and then separating the purified smoke from the absorbent. Water, aqueous salt solutions, and organic solvents are used as absorbents.

The absorption purification process consists of several stages: diffusion of the captured component from the gas mixture to the gas-liquid phase boundary, diffusion of the component in the film and its dissolution in the liquid phase, diffusion of the component from the film into the liquid phase volume. The determining parameter of the absorption process is the difference in concentrations at the smoke-liquid phase boundary. With an increase in the phase boundary surface area, flow turbulence, and diffusion coefficients, the sorption rate increases.

Absorption can be an open or a closed process. In an open process, the liquid absorbent is used once without desorption of the captured components. In a closed process, the absorbent circulates in the absorption-desorption system.

Various types of scrubbers are available, including cross-flow, counter-flow, direct-flow, spray, ionisation, and Venturi scrubbers. They differ in design and are intended for the separation of specific components from gas emissions.

Cross-flow scrubbers are used when it is necessary to separate dust and gases simultaneously, especially particles with a size of 10 microns. In such scrubbers, the gas flow passes through the filler layer in a horizontal direction, while the washing liquid is supplied from the nozzles at the top and flows into the drip tray at the bottom of the working chamber. From the drip tray, the water is pumped for recirculation or discharged into the sewer through a fitting.

Before leaving the chamber, the gas passes through another layer of filler, which is not wetted by the liquid and serves to separate liquid droplets from the purified gas. Scrubbers of this type can be multi-stage (two- or three-stage). All stages, including the preliminary separator, can be mounted inside a common apparatus housing. Such scrubbers are compact and occupy a small production area.

In counterflow scrubbers, the gases to be purified rise from bottom to top, and the washing liquid flows from top to bottom. A filler layer with a thickness of 800–1500 mm ensures effective (up to 98%) separation of easily soluble toxic gases, as well as finely dispersed droplets no larger than 5 microns. To separate

poorly soluble gases, the height of the filler layer should be 1–10 m. Counterflow scrubbers provide effective absorption of compounds such as Cl_2, ClO_2, NH_3, SO_2, etc.

In direct-flow scrubbers, the gas to be purified is fed into the lower part of the apparatus, while the filler is sprayed with water from below. The wash liquid flows into a tray located at the bottom of the scrubber and is pumped back to irrigate the filler layer until it is suitable for washing, and then discharged into the sewer.

In spray scrubbers, the washing liquid is sprayed to a finely dispersed state, thereby achieving the maximum possible effect of washing out impurities. Venturi scrubbers are recommended for separating finely dispersed droplets or solid particles ranging in size from 5 to 0.1 microns. As scrubbers, they are usually used only with the simultaneous separation of finely dispersed inclusions or to obtain a smoking liquid.

Physical absorption of gases, i.e. absorption with a pure solvent (usually water), does not provide a sufficient level of purification, so it is more often used in combination with chemisorption. Sulphuric acid, caustic soda, sodium hypochlorite and others are used as chemical reagents.

For cleaning and odour removal, horizontal and vertical absorption units manufactured by Fläkt (Denmark) are used, consisting of the following main elements: scrubbers (two and three stages), chemical dosing, neutralisation, recirculation and liquid spraying systems, fans, automation and control devices.

The first stage is designed to remove solid particles from the smoke-air mixture and absorb nitrogen compounds (ammonia, amines) by treating it with a recirculating washing liquid, which is sprayed by shower devices, and the washing liquid is filtered before it reaches the shower devices. The recirculation system is a complex of devices that ensure closed circulation of the washing liquid. This liquid is neutralised with 98% sulphuric acid, which is automatically added to the required pH value, after which it is discharged into the sewerage system. The second stage is designed to absorb and oxidise sulphur compounds (hydrogen sulphide and mercaptans), aldehydes, ketones, phenols and fatty acids.

The absorption of these mostly acidic compounds is facilitated by a high pH level (8.5–9.5), which is achieved by adding sodium hydroxide or sodium hypochlorite to the system, and a concentration of active chlorine at a level of 29–60 mg/dm^3. The system automatically controls the addition of the required amount of reagents depending on the degree of gas contamination of the emissions from the smoking installations. During the flue gas cleaning process, sodium hydroxide or sodium hypochlorite hydrolyses the complex esters of smoke, converting phenols and organic acids into easily soluble phenolates and sodium salts.

In the third stage, excess chlorine and acid compound residues are removed. This process is more effective at high pH levels. If hard water is added, $CaCO_3$ will form. If the process takes place at a pH of 9.5–10.5, soft water should be added.

Scrubbers are made of glass fibre reinforced polyester. For better smoke

distribution, guide plates and distribution grids are installed at the scrubber inlet. With this smoke emission cleaning system, the exhaust gases meet the guaranteed characteristics, and the amount of odorous substances does not exceed the permissible values. Abroad, lightweight plastic fillers are used in the design of gas cleaning installations in scrubbers.

Thus, effective flue gas cleaning is only possible with the use of chemically active liquid absorbents, which produce a large amount of aqueous salt solutions that can only be disposed of after additional treatment.

The methods currently used to clean flue gas emissions either have low neutralisation efficiency, which does not meet sanitary standards, or high cleaning costs. Therefore, in order to achieve a level of flue gas emissions concentration that meets sanitary requirements, it is necessary to use several cleaning methods in sequence, which determines the neutralisation or processing technology.

The choice of purification method is determined by its cost, the individual characteristics of the enterprise, the type of products manufactured, and a number of other factors. When choosing one method or another, economic considerations should be taken into account.

12.6 Utilisation of smoke emissions from smoking chambers

It is known that smoke emissions from smoking chambers contain significant amounts of organic compounds such as phenols, organic acids, and carbonyl compounds. In the process of neutralising smoke emissions, it is advisable to use purification methods that would allow for the utilisation of these substances. Of the known purification methods, the most acceptable is the absorption method at the stage of using fresh water. After appropriate purification of aqueous smoke solutions, smoking preparations can be obtained that can be used during liquid smoking of fish.

Of interest is a device developed by the Pivdenrybtsentr Scientific and Production Association. It consists of two sorbers capable of operating autonomously. First, the absorber is filled with 350–400 mm of water, then a high-pressure fan is turned on, creating a vacuum inside the sorber. The smoke-air mixture passes through a layer of water and enters under perforated grates, on which polyethylene balls are placed.

At the same time, the water and balls enter a state of pseudo-boiling, creating favourable conditions for interaction with smoke particles. For more complete purification, the smoke-air mixture, after passing through the pseudo-boiling layer, is additionally sprayed with water, which is then captured by droplet separators. The water level in the unit is maintained by means of flexible drain pipes. During the operation of the absorber, water heating is provided, as well as the possibility of draining waste water into the sewerage system or creating a recirculation system to control the water in the absorber. In this case, before being returned to the absorber, the water is filtered through a filter.

The capacity of the installation for a smoke-air mixture is 10,800–15,000 m^3/hour, water consumption is 5 m^3/hour, steam consumption at a pressure of

0.2 MPa is 80 kg/hour, and electricity consumption is 28 kWh. During the process of concentrating smoke emissions over a period of 5 hours, the water turns dark brown in colour with a characteristic pungent smell of smoke. The aqueous smoke solution after separation of resinous substances can be used as a smoking liquid.

Employees of scientific institutions have developed a method for obtaining a smoking preparation from the smoke emissions of smoking chambers using a Venturi scrubber.

The Venturi scrubber consists of a cyclone with a water regulator in the lower part, a Venturi tube, a ring water supply nozzle, a high-pressure fan, a recirculation pump, a recirculation water filter, a gate valve, valves of the smoke duct and water supply systems.

The main part of the scrubber is the Venturi tube, which, in order to reduce hydraulic losses, has a smooth narrowing at the inlet (confuser) and a smooth expansion at the outlet (diffuser). The narrowest part of the Venturi tube is called the throat. In addition, the Venturi tube includes a centrifugal swirler located behind the diffuser.

The unit operates as follows: first, a recirculation water filter is installed and the tank is filled with drinking water. Then the fan is turned on, and the smoke emissions from the smoking chambers are fed into the Venturi tube.

As the smoke flows through the confuser, its speed increases and reaches its maximum value in the throat. When water and smoke interact, the water is finely atomised and accelerated by the high-speed smoke flow at a speed close to that of the smoke flow. This causes the irrigation water droplets to collide with the smoke components and, as a result, trap them. After the throat, the smoke-air flow passes through a diffuser, where the flow velocity decreases, which increases the duration of contact between the smoke components and the water droplets. As a result, the smoke particles are further absorbed by the water.

The separation of water droplets occurs in the lower part of the Venturi tube with a significant reduction in speed and a change in the direction of the smoke-air flow created by the centrifugal swirler. At the same time, water droplets with captured smoke particles, having high inertia, do not keep up with the change in the direction of the flow and, moving in the original direction, hit the surface of the water and are captured by it.

From the Venturi tube, under the action of the centrifugal swirler, the flow is tangentially diverted into the cyclone and acquires a rotational motion there. At the same time, uncaught water droplets are thrown against the wall of the cyclone under the action of centrifugal forces and washed away by a film of water created by a ring water pipe.

The smoke emissions purified in this way are discharged into the atmosphere through the outlet manifold. The water in the unit is constantly recirculated by a pump until it is saturated with smoke components of a certain concentration, after which the aqueous smoke solution (smoking preparation) is drained into a storage tank and used for liquid smoking of fish. During the operation of the scrubber, part of the recirculating water is lost in the form of splashes and due to evaporation.

Water losses are automatically replenished with clean water. The unit is equipped with flow meters to control the total and recirculating water flow. The maximum recirculating water flow is 10 m3/hour. There is a gate valve device that allows you to change the volume of smoke emissions to be cleaned, depending on the amount of smoke emitted by the smoking chamber into the atmosphere. Since the aqueous smoke solution has an acidic reaction, all parts of the installation that come into contact with the smoking agent must be made of corrosion-resistant material, such as stainless steel.

The unit's capacity is 3000 m^3/hour, its installed power is 8.4 kW, its maximum hydraulic resistance is 5 kPa (500 mm water column), and the temperature of the smoke being cleaned is up to 95 ^{0}°C, water consumption during one cleaning cycle – 0.25 m^3. The duration of the process is about 8 hours.

The smoking preparation is poured into storage containers, settled for 8 – 10 days, and filtered through 8 layers of gauze to remove water-soluble resins. The smoking preparation has the following chemical composition: pH – 3.56; optical density – 2.03; mass fraction of phenols – 0.19%, total acidity – 0.028. It is a transparent bright golden liquid with a pleasant smoky aroma.

When using a Venturi scrubber as a purification facility, the degree of purification of smoke emissions is 90–95%. Thus, the use of a Venturi scrubber to purify smoke emissions from smoking installations and obtain smoking preparations will make it possible to combine the solution of environmental problems with the creation of low-waste and waste-free technologies.

Questions for discussion and self-assessment

1. Describe the nature of smoke and its chemical composition.
2. Physical properties of smoke, its dispersed composition.
3. What proportion of smoke emissions from smoking chambers is of the total amount of smoke generated, and what chemical indicator is used to assess the degree of smoke emission purification?
4. What is the essence of the water-inertial method of smoke purification?
5. Describe the scheme of the thermal (fire) method of smoke emissions neutralisation from smoking chambers.
6. List the existing methods of thermal neutralisation of smoke emissions from smoking chambers and the features of the catalytic method.
7. What is the essence of the process of electrical purification of smoke emissions? How does their dispersed composition affect the degree of purification?
8. Explain the concept of a "wet electrostatic precipitator".
9. The essence of the adsorption method of smoke emission purification. What adsorbents are used?
10. Explain the concept of "adsorbent in a fluidised state". What is the advantage of this adsorbent compared to an adsorbent in a boiling state?

11. What is the efficiency and availability of the adsorbent in a fluidised state?
12. Describe the features of the absorption method of flue gas purification.
13. What are the methods of supplying a smoke-air mixture to absorbers and scrubbers, and what are the reasons for this?
14. Write down the methods of flue gas purification using chemisorption.
15. What chemicals (other than water) are used in chemisorption?

CHAPTER 13. BIOSAFETY AND BIOSECURITY REQUIREMENTS FOR LABORATORY WORK

Locating the laboratory in a specially designated room ensures proper sanitary conditions in all work areas. In this case, the basic requirements for room lighting, the installation of fume cupboards and their equipment, and the entire laboratory's supply and exhaust ventilation are met. In addition, the correct placement of laboratory equipment and instruments is provided for, and therefore their rational use. Laboratory staff must be highly qualified and have practical skills. Since many laboratory tasks require special precautions, it is necessary for all employees to have training and knowledge of biosafety and biosecurity.

In laboratories operating at treatment plants, great importance is attached to safe working methods. Training for all employees is conducted annually. The training programme includes basic information on occupational safety and Ukrainian legislation, rules for safe work in the laboratory, at the treatment plant, on water bodies and at industrial enterprises. In addition, there is a special section on accidents in the laboratory and first aid. Theoretical and practical classes in this section are conducted by a medical professional. Classes are conducted according to an approved programme, end with a test of knowledge and are recorded in a protocol.

Throughout the year (2 – 4 times), training is conducted directly at the workplace, taking into account the specifics of the work in that area. During practical classes, employees learn how to use fire extinguishers and fire hoses; compliance with instructions is checked (working with autoclaves, gas cylinders, etc.). The training is recorded in a special logbook, indicating the topic of the training, the name of the employee who conducted the training – the head of the laboratory (responsible for safety), his deputy, the group engineer (foreman).

Brief instructions containing a list of safe practices for the main types of work and fire prevention measures must be posted at workplaces. Laboratory staff must work in lab coats, and in some cases (when diluting acids, alkalis and transferring them in large quantities) must wear safety goggles, rubber gloves, a rubberised apron and rubber boots. Reagents and materials must be stored in the laboratory in accordance with their specific characteristics. Concentrated acids, alkalis and other reagents that emit harmful vapours and gases are stored in small quantities only in fume cupboards, in glass bottles with ground stoppers and protective caps. The main stocks of these reagents are stored in a separate concrete basement.

Workplaces contain non-hazardous reagents in quantities necessary for analysis. Flammable reagents (ether, petrol, benzene, alcohol) must be stored in a separate cool room or in a metal cabinet and issued only on the day of analysis in limited quantities, not exceeding 200 ml. Fire-hazardous substances must be handled with extreme caution, as their vapours can spread over long distances and ignite. In the room where the analysis is carried out, burners should not be lit and

other heat sources should be used sparingly. If heating is necessary or during the distillation of flammable substances, a preheated water bath should be used.

To work with poisons, you must obtain permission from the relevant organisations and instructions for their use and storage. One employee is responsible for the storage, issuance and accounting of toxic substances. Employees familiar with the rules for working with poisons must work with toxic substances in a separate room under a fume hood. After finishing work, the workplace should be thoroughly cleaned, and the dishes should be sent for washing after being decontaminated.

When working with gas burners and electric heating devices, which are often used in the laboratory, the following precautions must be observed: the gas network, taps, burners and rubber tubes that carry away gas must be in good working order. The gas in the laboratory is turned on and off by one responsible employee who keeps the key.

When using electric heating devices, it is necessary to monitor the condition of electrical wiring, plugs and sockets. Despite the above precautions when working with flammable substances and heating devices, the possibility of a fire cannot be ruled out. Therefore, the laboratory must always have dry sand in all work areas, sheet asbestos, a sufficient number of fire extinguishers in designated locations, and fire hoses. All employees must know that in case of ignition of petrol, turpentine, alcohol, etc., water cannot be used, as well as for extinguishing sulphuric acid. Given the specific nature of laboratory work at treatment facilities, it is important to know that wastewater and sludge pose a significant health hazard to workers. Therefore, all operations related to the sampling of wastewater and sludge and their preparation for analysis require compliance with sanitary precautions. Direct contact with wastewater must be avoided when performing certain operations, and hands must be washed thoroughly after work. When measuring wastewater with pipettes, only rubber bulbs should be used; sucking water with your mouth is strictly prohibited. When sorting waste for analysis, it is necessary to work with rubber gloves and wear safety goggles. It is prohibited to eat at workplaces and use laboratory utensils for this purpose.

Precautions when sampling and collecting sediments

In addition to automatic sampling, manual sampling is also carried out at treatment facilities. Sampling locations are determined in advance and all measures are taken to ensure safe working conditions at any time of the day (lighting, fencing, safe crossings, etc.).

Containers and equipment intended for sampling and transporting samples (glasses, buckets, boxes, ladles) must always be in good condition.

Requirements for sampling from water bodies

Samples from water bodies shall be taken at pre-determined points or at locations specified by the person responsible for the work. This employee is responsible for the organisation and safe performance of work on the water body, the correct use of motor vehicles and the work discipline of all participants;

accordingly, all participants involved in the work on the water body must unquestioningly follow his instructions. The number of participants depends on the scope of the work to be done, but cannot be less than 2 people. It is necessary to have a car with a driver to deliver samples, transport people, equipment, inventory and rescue equipment (individual rescue equipment: rings, inflatable vests).

During sampling, a strong 25 m rope must always be at hand, and in winter, in addition to an ice axe, several boards. On the eve of departure, each participant in the water body survey must have a clear plan of the work to be done and carefully prepare everything necessary: dishes, reagents, instruments, etc. On site, all employees undergo training on the rules of conduct on the water body and precautions during the performance of certain works.

Before starting the work itself, it is necessary to obtain information about the nature of the reservoir being surveyed in advance from the relevant organisations (water inspectorates, rescue stations and other institutions) and, as a last resort, from local residents (fishermen, river fleet workers). Depending on the season, it is necessary to know the speed of the current, depth, eddies, prevailing direction, wind strength, etc. In winter, if the water body freezes, it is necessary to have information about the ice cover, ice thickness, areas that do not freeze, and work carried out that may disrupt the usual understanding of the water body.

It is absolutely necessary to have a weather forecast for the day of work on the water body. The choice of transport for future work is of great importance, especially for large rivers and reservoirs. In the absence of a special vessel, a river boat can be used, provided that the instruments, equipment and rescue equipment can be safely and conveniently placed for work. On small, calm water bodies, where you have to travel relatively short distances, you can use boats - motor or rowing. In both cases, an experienced driver who is well versed in the rules of movement on the water body or has the appropriate licence (motorist) is required. All participants in the trip must have general and individual rescue equipment.

Sampling at industrial enterprises. When sampling industrial effluents at different enterprises, their specific characteristics should always be taken into account. To this end, it is necessary to obtain information about the composition of the effluents in advance from the enterprise and pay attention to particularly toxic components. Before sampling effluents for analysis, it is necessary to obtain detailed instructions from local specialists, as well as information on safe places for sampling (the participation of local employees is mandatory).

Two people should take samples from wells. After removing the cover, the wells must be thoroughly ventilated for a long time. The work should be organised in such a way that workers (using protective equipment) inhale as little harmful vapours and toxic gases as possible. To do this, you need to prepare containers and equipment for quick sampling, taking into account the depth of the well. All workers should be instructed on how to transport and prepare samples for analysis.

Questions for discussion and self-assessment

1. Where are laboratories located?
2. What should staff have when working in a laboratory?
3. Why is safety important when working in laboratories?
4. How is training provided for all employees?
5. What is displayed in the workplace?
6. What do the instructions contain?
7. How are reagents and materials stored in the laboratory?
8. How are concentrated acids stored?
9. How are alkalis stored?
10. How are reagents that emit harmful vapours and gases stored?
11. What is required to work with poisons?
12. What should be monitored when using electric heating devices?
13. How are samples taken from water bodies?
14. Where are samples taken from water bodies?

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National Standard of Ukraine: Drinking water requirements and quality control methods: DSTU 7525:2014 *(effective from 2015-02-01)*

SCOPE

This standard applies to drinking water from centralised and non-centralised water supply systems, including bottled and non-bottled water.

This standard is recommended for use by:

- business entities that produce drinking water through centralised drinking water supply or at water bottling points (in particular, pump rooms and mobile ones), using installations (devices), other means of non-centralised water supply, bottling of drinking water:
- executive authorities;
- drinking water supply companies that regulate, supervise and control the quality of drinking water;
- consumers of commercial drinking water.

This standard does not apply to mineral medicinal waters, medicinal-table waters, natural table waters, as well as bottled water containing specific medicinal substances (iodine, fluorine, selenium, etc.) for special dietary consumption by children, patients and athletes.

TERMS AND DEFINITIONS

This standard uses the terms established in the Law of Ukraine "On Drinking Water and Drinking Water Supply": drinking water production, centralised drinking water supply, decentralised drinking water supply, drinking water supply enterprise, drinking water supply system, packaged drinking water, drinking water bottling point, individual and collective drinking water supply installations (devices), drinking water consumer the term established in Council Directive 98/83/EC is used: drinking water intended for human consumption; the terms established in DSTU ISO 6107 (all parts) are used: water for water supply, water quality criteria; the term established in DSanPiN 2.2.4-171 is used: drinking fountain; the terms established in DSTU 3041 are used: standard, indicator of water composition and properties, water monitoring.

ABBREVIATIONS AND ABBREVIATIONS

BGKP – Escherichia coli bacteria,
Bq – becquerel;
BUO – plaque-forming units;
CMN – total microbial number (number of saprophytic microorganisms);
CFU – colony-forming units
NOC – nephelometric turbidity units;
SAS – synthetic surfactants;
TSB – thermostable intestinal bacteria.

GENERAL PROVISIONS

1. This standard contains drinking water quality standards and establishes requirements for methods of its control in centralized and decentralized drinking water supply.

2. Sources of decentralised drinking water supply are considered to be groundwater, drinking water from centralised drinking water supply systems, purified using effective modern conditioning technologies.

3. The main conditions for ensuring drinking water quality standards in centralised water supply systems are as follows:

- selection of centralized drinking water supply sources in accordance with the requirements of DSTU 4808;
- protection of sources and centralised drinking water supply systems from contamination;
- compliance with the requirements of the technological regulations for water supply systems;
- use of equipment, devices, materials and reagents in centralised drinking water supply systems that are approved by the central executive authority responsible for shaping state policy in the field of health care.

4. The main conditions for ensuring the quality standards of drinking water in non-centralised water supply are as follows:

- carrying out the technological process of drinking water treatment in accordance with the technological instructions or technological regulations;
- taking into account the quality of water from underground sources of drinking water supply or water from centralised water supply systems;
- compliance of the degree of additional purification of drinking water with the regulatory requirements of this standard for the quality of bottled drinking water;
- use of containers and disinfection means for bottled drinking water approved by the central executive authority responsible for shaping state policy in the field of health care.

5. The compliance of drinking water quality with the requirements of this standard shall be established taking into account the documents regulating the rules for the operation of water supply systems.

REQUIREMENTS FOR THE QUALITY INDICATORS OF DRINKING WATER INTENDED FOR HUMAN CONSUMPTION

1. The requirements and standards for the composition and properties of drinking water determine its suitability for satisfying the physiological, sanitary, hygienic, domestic and economic needs of humans and cover: the safety of water in terms of epidemics, the harmlessness of its chemical composition, favourable organoleptic properties, toxicological and radiation safety.

2. The list of indicators and standards for drinking water quality is based on the principle of not exceeding the normative values and values of physical, organoleptic, chemical, microbiological, toxicological and radiation indicators for

drinking water established in this standard and in DSanPiN 2.2.4-171.

3. The list of quality indicators for drinking water intended for human consumption is determined in this standard depending on the water supply source, secondary contamination due to the use of reagents in the water treatment process, and assessment of the toxicity level of water from non-centralised drinking water supplies. For packaged water from non-centralised drinking water supplies, the same list of indicators is maintained as for unpackaged water from non-centralised drinking water supplies.

The requirements for the quality of water from centralised and non-centralised drinking water supplies cover 82 indicators and are presented in 10 separate groups: Group 1 – 8 microbiological indicators; Group 2 – 1 virological indicator; Group 3 – 2 parasitological indicators; Group 4 – 1 mycological indicator; Group 5 – 4 toxicity indicators; Group 6 – 2 radiation safety indicators; Group 7 – 4 organoleptic indicators; Group 8 – 17 chemical quality indicators that affect the organoleptic properties of drinking water; Group 9 – 30 toxicological indicators of the harmlessness of the chemical composition (of which: 22 inorganic, 6 organic components and 2 integral indicators); Group 10 – 13 substances that are formed and enter drinking water during water treatment.

4. In terms of microbiological, virological and parasitological indicators, drinking water must comply with the requirements set out in Tables 1–3 and the standards of DSanPiN 2.2.4-171.

Table 1. Microbiological indicators of drinking water quality

Indicator	Unit of measurement	Standard, no more than	
		Water from the central water supply system	Non-centralised water
Number of bacteria in 1 cm³ of water tested (CMU) at 37 °C	CFU/cm³	100[1]	20[1]
Number of bacteria in 1 cm³ of test water (ZMC) at 22 °C	CFU/cm³	Not determined	20[1]
Number of bacteria of the Escherichia coli group (coliform microorganisms) in 1 dm³ of the water being tested (BGK index)	CFU/dm³	3[2]	Absence[2]
Number of thermostable coliform bacteria (faecal coliforms – FC index) in 100 cm³ of the water being tested	CFU/100 cm³	Absence [3]	Absence[3]
Number of pathogenic microorganisms in 1 dm³ of water being tested	CFU/dm³	Absence [3]	Absence [3]
Number of coliphages in 1 dm³ of water being tested	COD/dm³	Absence [3]	Absence [3]
Spores of sulphite-reducing clostridia	Present	Absent [4]	Absence [4]

	(number) /20 cm³		
Pseudomonas aeruginosa	CFU/dm³	Not determined	Absence

[1] Exceeding the standard is not permitted for 95% of water samples in the water supply network tested during the year.

[2)] Exceeding the standard is not permitted for 98% of water samples in the water supply network, which are tested during the year. If the BGCP index is exceeded at the stage of identifying the grown colonies, additional tests are carried out for the presence of faecal coliforms.

[3]If coliform bacteria and/or coliphages are present in the water sample, their number is urgently determined in re-sampled water samples. If total coliform bacteria in an amount of > 2/100 cm[3] and/or thermostable coliform bacteria and/or coliphages are detected in these samples, pathogenic bacteria of the intestinal group and/or enteroviruses are determined. Drinking water shall also be tested for the presence of pathogenic bacteria of the intestinal group and enteroviruses by decision of the relevant authorities in the event of an epidemic situation.

[4]Controls are carried out at the outlet of the drinking water treatment plant in the case of surface water sources or underground sources that are hydraulically connected to surface water bodies. During the transition period each year, an indicator is added to the controls: sulphite-reducing clostridia spores with a standard of Absence/20 cm[3]

Table 2. Virological indicators of drinking water quality

Indicator	Unit of measurement	Standard, no more than	
		Water system central water supply	Non-centralised water
Enteroviruses, adenoviruses, rotaviruses, reoviruses and hepatitis A virus antigen	BUO/dm³	Absence	Absence

Table 3. Parasitological indicators of drinking water quality

Indicator	Unit of measurement	Standard, no more than	
		Water from the central water supply system	Non-centralised water
Number of pathogenic intestinal protozoa in 50 dm³ of water being tested	(Cells, cysts)/ 50 dm³	Absence[1]	Absence [1]
Number of intestinal helminths in 50 dm³ of water being examined	(Cells, eggs, larvae)/ 50 dm³	Absence [1]	Absence [1]

[1)] Determined once a year during a complete water analysis and according to epidemiological indicators

5. According to mycological indicators (micromycetes), drinking water must comply with the standards set out in Table 4.

Table 4. Mycological indicators of drinking water quality

Indicator	Unit of measurement	Standard, no more than	
		Water from the central water supply system	Non-centralised water
Microfungi	CFU/100 cm³	Absence	Absence[1]

[1)] There should be no *Aspergillus fumigatus* at all. *Aspergillus niger, Penicillum expangum*

The toxicity level of drinking water from non-centralised water supply is an integral (express) indicator of drinking water quality in case of suspected contamination of the water source or distribution network with toxic compounds. The list of indicators and test objects, as well as standards for determining toxicity based on the results of biotesting, are given in Table 5.

Table 5. Level of toxicity of drinking water

Indicator	Unit of measurement	Standard, no more than	
		Water system central water	Non-centralised water
Chronic toxicity to *Ceriodaphnia affinis*	Number of dead individuals and/or reduction in the number of newborn individuals in the experiment compared to the control after (7±1) days	Not determined	No chronic toxicity
Toxicity on *Tetrahymena pyriformis*	Decrease in the growth rate of ciliates in the experiment compared to the control over a set period of time – 24 hours (short-term biotesting) or 96 hours (long-term biotesting)	Not determined	No toxicity
Cytotoxicity according to the leukocyte formula of the blood of Danio rerio (Brachydanio rerio Hamilton-Buchanan)	%	Not determined	10
Genotoxicity in blood cells of Danio rerio (Brachydanio rerio Hamilton-Buchanan) fish	%	Not determined	0.33

7. The radiation safety of drinking water is determined by the permissible levels given in Table 6.

Table 6. Radiation safety indicators for drinking water

Indicator	Unit of measurement	Standard, no more than	
		Water system central water supply	Non-centralised water
Total volume activity of α-emitters (∑α-activity)	Bq/dm³	0.1	0.1
Total volume activity of β-emitters (∑β-activity)[1,2]	Bq/dm³	1.0	1.0

[1)] If the levels of ∑α- and ∑β-activity are exceeded, the radionuclide composition of water must be monitored for compliance with the radiation safety standards specified in [1].

[2] If the level of ∑β-activity is exceeded, it is also necessary to take into account the potassium content in water, since ∑β-activity is caused not only by technogenic radionuclides, but also by natural isotopes, in particular (40) K (1 Bq of ∑β-activity corresponds to a potassium content of 35.4 mg K+/dm³ in water). Therefore, if ∑β-activity is ≥ 1 Bq/dm³, it is necessary to first determine the potassium content using atomic emission spectroscopy, followed by detailed radiological studies (the relationship between the specific beta activity of the samples studied and their potassium concentration is linear; in a natural mixture of potassium isotopes, radioactive (^{40}K accounts for 0.0119%).

8. According to organoleptic indicators and chemical quality indicators that affect organoleptic properties, drinking water must comply with the standards given in Tables 7–8 and the norms of DSanPiN 2.2.4-171.

Table 7. Organoleptic quality indicators for drinking water

Indicator	Units of measurement	Standard, no more than	
		Water system central water supply	Non-centralised water
Organoleptic indicators of drinking water quality			
Odour at 20°C	Points	2	0
Odour when heated to 60 °C	Points	2	1
Taste and aftertaste	Points	2	0
Colour	Degrees	20(35)	5
Turbidity	NOC	1.0(3.5)[1] 2.6(3.5)[1,2]	0.5

[1)] The value indicated in brackets may be established by a resolution of the relevant authority in the relevant territory for a specific drinking water supply system based on an assessment of the sanitary and epidemiological situation in the settlement and the drinking water treatment technology used when other sources of drinking water are not available

[2)] For underground water sources

Table 8. Chemical indicators affecting the organoleptic properties of drinking water

Indicator	Unit of measurement	Standard, no more than	
		Water system central water supply	Non-centralised water water
Inorganic components			
Hydrogen index (pH) within	pH units	6.5 – 8.5	6.5 – 8.5
Dry residue (total mineralisation) optimal content, within the range	mg/dm³	1000 (1500)[1]	1000 200 – 500
Total hardness optimal value, within the range of	mmol/dm³	7(10)[1]	7 1.5 – 7
Alkalinity total optimal value, within the range of	mmol/dm³	Not determined	6.5 0.5 – 6.5
Sulphates	mg/dm³	250(500)[1]	15
Chlorides	mg/dm³	250(350)[1]	15
Total iron (Fe)	mg/dm³	0.2(1.0)[1]	Absence
Manganese (Mn)	mg/dm³	0.05(0.5)[1]	Absence
Copper (Cu)	mg/dm³	1	Absence
Zinc (Zn)	mg/dm³	1	Absence
Calcium (Ca)	mg/dm³	Not determined	13 25
Magnesium (Mg) Optimal content, within the range of	mg/dm³	Not determined	80 10
Sodium (Na) optimal content, within the range of	mg/dm³	20	20 2
Potassium (K) optimal content, within the range of	mg/dm³	Not determined	2 2
Organic components			
Petroleum products	mg/dm³	0	Absence
Volatile phenols	mg/dm³	0.001	Absence
Chlorophenols	mg/dm³	0.0003	Absence

[1)] The value indicated in brackets may be established by a resolution of the relevant authority in the relevant territory for a specific drinking water supply system based on an assessment of the sanitary and epidemiological situation in the settlement and the drinking water treatment technology used when other sources of drinking water are not available.

9. In terms of toxicological indicators of the safety of its chemical composition, drinking water must comply with the standards set out in Table 9 and the norms of DSanPiN 2.2.4-171.

Table 9. Toxicological indicators of drinking water[1]

Indicator	Units of measurement	Standard, no more than	
		Water system central water supply	Non-centralised water
Inorganic components			
Aluminium (Al)	mg/dm³	0.2(0.5)[2]	Absent
Ammonia (as NH_4^+)	mg/dm³	0.5(2.6)2	Absence
Barium (Ba)	mg/dm³	0	0.1
Beryllium (Be)	mg/dm³	0.0002	Absent
Boron (B)	mg/dm³	0.5	Absent
Cadmium (Cd)	mg/dm³	0.001	Absence
Cobalt (Co)	mg/dm³	0.1	Absence
Arsenic (As)	mg/dm³	0.0	Absence
Molybdenum (Mo)	mg/dm³	0.07	Absent
Nickel (Ni)	mg/dm³	0.02	Absence
Nitrates (as NO_3^-)	mg/dm³	5	5
Nitrites (as NO_2^-)	mg/dm³	0.5(0.1)[3]	0.02
Perchlorates (ClO_4^-)	mg/dm³	0.01	Absence
Mercury (Hg)	mg/dm³	0.0005	Absent
Lead (Pb)	mg/dm³	0.01	Absence
Selenium (Se)	mg/dm³	0.01	Absence
Strontium (Sr)	mg/dm³	7	2
Antimony (Sb)	mg/dm³	0.005	Absent
Thallium (Ti)	mg/dm³	0.0001	Absence
Fluorides (F^-) for climatic regions II III IV	mg/dm³	 1.5 1.2 0.7	 1.5 1.2 0.7
Total chromium (Cr)	mg/dm³	0.05	Absence
Cyanides (Cn-), in particular cyanogen chloride	mg/dm³	0.05	Absence
Organic components			
Benz(a)pyrene	mg/dm³	0.000 005	Absence
Benzene	mg/dm³	0.01	Absence
Pesticides (total)	mg/dm³	0.0005	Absence
Synthetic anionic surfactants (APAR)	mg/dm³	0.5	Absence
Trichlorethylene and tetrachlorethylene (total)	mg/dm³	0.01	Absence
Carbon tetrachloride	mg/dm³	0.002	Absence
Integral indicators			
Permanganate oxidisability	mg O/dm³	5	0.75
Total organic carbon	mg O/dm³	8	1.5

[1)] If several chemicals classified as safety classes 1 and 2 and having sanitary and toxicological signs of harmfulness are detected in drinking water, the sum of the ratios of the concentrations of each of them in water to their standard values shall not exceed 1.

[2)] The value indicated in brackets may only be established by a decision of the relevant authority in the relevant territory for a specific drinking water supply system based on an assessment of the sanitary and epidemiological situation in the settlement and the drinking water treatment technology used, taking into account the specific situation.

[3)] The standard indicated in brackets is set for treated drinking water, except for water treated by chlorination with pre-ammoniation.

[4)] The standard for fluorides in drinking water is given in accordance with DSanPiN 2 2.4-005.

[5]"Pesticides, total" means: organic insecticides, herbicides, fungicides, nematicides, acaricides, algaecides, bactericides, virucides, rodenticides, slime control agents, related products (in particular growth regulators), as well as metabolites and degradation products. Only pesticides that are likely to be present in the water are included in the monitoring programme.

10. For water supply systems that use reagent methods to treat water before it is supplied to the distribution network, during bottling, transportation, storage and throughout the established shelf life, the indicators specified in Table 6.10 shall be additionally taken into account when conducting studies. The content of substances formed and entering drinking water during water treatment shall not exceed the standards specified in Table 10.

Table 10. Substances formed and entering drinking water during preparation

Indicator[1]	Units of measurement	Standard, no more than	
		system water Central water	non-centralised water
Acrylamide[2]	mg/dm³	0.0001	Absent
Bromates	Mg/dm³	0.01	Absence
Residual chlorine dioxide	Mg/dm³	0.1	Not determined
Residual ozone within limits	mg/dm³	0.1-0.3	Absent
Residual polyphosphates (PO_4^{3-})	mg/dm³	3	Absence
Trihalomethanes: chloroform, bromoform, dibromochloromethane, bromodichloromethane (total)	Mg/dm³	0.1	Absence
Formaldehyde	Mg/dm³	0.05	Absence
Residual free chlorine	mg/dm³	0.5	Absence
Residual bound chlorine	mg/dm³	1.2	Absence
Chlorate ion	Mg/dm³	0.7	Absence
Chlorite ion	Mg/dm³	0.2	Absence
Chloroform	mg/dm³	0.06	Absence
Dichlorobromomethane	Mg/dm³	0.01	Absence

[1)] Specific indicators are included in the control programme from the above list, taking into account the water treatment technology.

[2)] Included in the control programme when using the relevant reagents and determined by calculation based on the analysis of the monomer content in the commercial flocculant. Reagent doses and monomer levels must meet the following requirements for polyacrylamide doses of 1 mg/dm³: the acrylamide content must not exceed 0.05%.

[3)] The concentration of residual ozone in drinking water at the outlet of the mixing chamber shall be within the range of 0.1–0.3 mg/dm^3 for a contact time of at least 4 minutes.

11. The quality indicators of centralized and decentralized drinking water supplies shall be monitored using the testing methods specified in Annex A.

PROCEDURE FOR STATE AND PRODUCTION CONTROL OF WATER QUALITY IN CENTRALISED DRINKING WATER SUPPLY SYSTEMS

1. State control of drinking water quality is carried out by local self-government bodies, local executive authorities in the field of standardisation and state sanitary and epidemiological surveillance bodies, and industrial control is carried out by water supply and sewerage companies in accordance with current legislation.

2. The objects of state control for centralised water supply systems in terms of water quality are: water during the months of water intake, during treatment at treatment facilities, before entering the external distribution network, and in the internal water supply system. When determining the procedure for state sanitary and hygienic supervision of drinking water quality in centralized water supply systems, the basic provisions of DSanPiN 2.2.4-171 should be followed.

3. Production control of water quality in centralized drinking water supply systems is carried out in accordance with technological regulations agreed with the sanitary- epidemiological service, taking into account the natural and climatic characteristics of the region, its ecological and sanitary-epidemiological status, and the technology of drinking water production in centralized water supply systems.

4. Production control of water quality in centralized drinking water supply systems is carried out depending on the volume of water produced and the capabilities of the laboratory in accordance with production control programs, which are developed separately for each centralized drinking water supply enterprise and agreed with the state sanitary and epidemiological surveillance authorities. The procedure for production control is determined by the technological regulations and is an integral part thereof. For small settlements, where water supply and sewerage enterprises do not have a laboratory base, the quality of drinking water can be controlled by enterprises on a contractual basis.

5. Production control of water quality in centralised drinking water supply systems is carried out in accordance with the technological regulations of the centralised drinking water supply enterprise:

- at water intake points:
- during water treatment at water treatment facilities;
- before water enters the distribution network;
- at water distribution points in the distribution network.

6. Groups of indicators, sampling frequency and number of samples of centralised drinking water supply are determined for water analysis at water intake points from surface and underground sources of centralised drinking water supply in accordance with the requirements of DSTU 4808. Additional studies are carried out in the event of significant pollution entering the water body as a result of heavy rainfall, man-made accidents, etc.

7. Production control of the quality of water in centralized drinking water supply systems in each specific case is established by technological regulations

and carried out by laboratories certified for this type of activity in accordance with the procedures established by current legislation using the methods specified in this standard in accordance with Appendix A.

8. Samples are collected, preserved and stored to determine the quality indicators of centralised drinking water supply in accordance with the requirements of DSTU ISO 5667.

PROCEDURE FOR PRODUCTION CONTROL OF WATER QUALITY IN NON-CENTRALISED DRINKING WATER SUPPLY

1. The objects of production control of water quality for non-centralised water supply are:

- water from non-centralised drinking water supply sources (groundwater, mine wells, inter-layer pressure wells) – without additional treatment;
- water from decentralised drinking water supply sources before and after additional treatment at water treatment and bottling points;
- water from decentralised drinking water supply sources at the stages of water treatment, before bottling in containers in the production of packaged drinking water.

2. The quality standards for non-centralised drinking water supply, as set out in Tables 1–10, must be ensured by the drinking water producer who supplies it to consumers or bottles it.

3. The quality standards for non-centralised drinking water supply are the same for water obtained by consumers through bottling at the place of production and for packaged water.

4. The quality indicators of non-centralised drinking water supply shall be monitored using the testing methods specified in Appendix A.

5. The quality of unpackaged and packaged water from decentralised drinking water supplies must comply with quality standards during bottling, transportation, storage and throughout the established shelf life in accordance with current legislation.

6. Production quality control of packaged water from decentralised drinking water supplies shall be carried out in accordance with the work programme, which is part of the document describing the technological process of packaged drinking water production.

7. Laboratory testing of water from non-centralised drinking water supplies shall be carried out in laboratories certified in accordance with DSTU ISO/IEC 17025 using certified and approved methods in accordance with Annex A.

8. The results of production control shall be stored at the enterprise or water intake point of non-centralised drinking water supply for the period specified by the product quality and safety assurance system.

9. Samples of non-centralised drinking water supply, which is bottled directly in the consumer's container or packaged for sale, shall be taken for control and monitoring at the point of bottling in the container or in the circulation of the

final product for packaged water (during storage, transport, sale, use) in accordance with the requirements in Table 11.

Table 11. Number of samples of non-centralised drinking water supply, packaged for control, depending on the volume of water produced

No.	Volume of water produced each day. m^3	Number of samples for control monitoring per year ( )	Number of samples for audit monitoring per year
1	Less than or equal to 10	1	1
2	More than 10	24	1
3	More than 60	24 1 per 5 m^3 and its share in the total volume (or 1, $\frac{total\ volume}{5}$)	1 per 100 m^3 and its share in the total volume (or 1, $\frac{total\ volume}{100}$)

10. Determine the groups of indicators, sampling frequency and number of samples of non-centralised drinking water supply for water analysis at the points of entry for additional treatment in accordance with Table 12.

Table 12. Frequency of sampling and determination of water quality indicators for non-centralised drinking water supply at water intake points

Groups of drinking water quality indicators	Frequency of sampling and minimum number of samples per year	
	Non-centralised water supply	Underground sources
Microbiological	12 (monthly)	4 (quarterly)
Virological	12 (monthly)	4 (quarterly)
Parasitological	12 (monthly)	Not performed
Mycological	12 (monthly)	4 (quarterly)
Toxicity level	—	4 (quarterly)
Radiation safety	1 (annually)	1 (annually)
Organoleptic	12 (monthly)	4 (quarterly)
Chemical, affecting organoleptic properties	12 (monthly)	4 (quarterly)
Toxicological indicators of chemical composition safety	12 (monthly)	1 (quarterly)

11. Groups of indicators, sampling frequency and number of samples of non-centralised drinking water supply for water analysis at the points of water supply to consumers after additional treatment during self-distribution of water are determined in accordance with Table 13.

12. Samples for determining the quality indicators of non-centralised drinking water supply shall be collected, preserved and stored in accordance with the requirements of DSTU ISO 5667.

Table 13. Frequency of sampling and determination of water quality indicators for non-centralised drinking water supply at water distribution points

Groups of drinking water quality indicators	Frequency of sampling and minimum number of samples per year (population of up to 20,000 people)
Microbiological	50 (weekly)
Virological	50 (weekly)
Parasitological	Not performed
Mycological	50 (weekly)
Toxicity level	4 (quarterly)
Radiation safety	1 (annually)
Organoleptic	50 (weekly)
Chemical, affecting organoleptic properties	50 (weekly)
Toxicological indicators of chemical composition safety	1 (annually)
Other indicators	Residual ozone – at least once per hour, other reagents (according to Table 6.9) – at least once per shift

SPECIAL ADDITIONAL REQUIREMENTS FOR PRODUCTION QUALITY CONTROL OF BOTTLED WATER NON-CENTRALISED DRINKING WATER SUPPLY

1. The production, processing, packaging and transportation of packaged water from non-centralised drinking water supply must be controlled in accordance with the requirements of this standard.

2. The labelling of bottled water from non-centralised drinking water supply shall comply with the requirements of DSTU 4518. The label shall indicate:

- its name, type, composition characteristics and quality indicators (dry residue, presence and concentration of preservatives, etc.);
- storage conditions, date of manufacture, shelf life;
- the name, address and telephone numbers of the manufacturer;
- place of manufacture;
- batch number, etc.

If the water is obtained from a centralised water supply system, treated and then packaged, the label must bear the words "from tap water".

3. Reagents that are permitted as preservatives for drinking water are listed in Table 14. It is prohibited to use other substances and methods for preserving packaged water from non-centralised drinking water supplies, except for the addition of carbon dioxide and silver ions.

4. It is not permitted to use any information or graphic images on the label of packaged water from non-centralised drinking water supplies that could lead to a misunderstanding by the consumer of its origin, nature, composition or properties.

Table 14. Reagents permitted as preservatives for drinking water

Preservatives	Units of measurement	Permissible mass fraction of preservatives in water, not more than
Silver (Ag)	mg/dm^3	0.025 (0.05)[1]
Carbon dioxide (CO_2)	%	0.2 – 0.6[2]

[1] For water with a chloride ion content of more than 50 mg/dm^3

[2] According to DSTU 878

5. It is not permitted to provide any information on the label regarding the therapeutic effects of packaged water from non-centralised drinking water supplies.

6. It is permitted to highlight the manufacturer's own name or logo in larger font or colour for packaged water from non-centralised drinking water supplies.

PROCEDURE FOR EVALUATING THE RESULTS OF WATER QUALITY RESEARCH OF CENTRALISED AND NON-CENTRALISED DRINKING WATER SUPPLY

1. The results of state control of the quality of drinking water for each sample shall be recorded in a separate protocol: for centralised drinking water supply – in the form of a report established by the competent organisation of Ukraine, and for non-centralised drinking water supply – in the form presented in Appendix B. The results of production control shall be recorded in special journals.

2. The conclusion on the compliance of drinking water quality with the standards of this standard and its suitability for human consumption, signed by officials, shall be submitted to the drinking water supply company for decisions on improving the operation of the water treatment plant. The conclusion may include recommendations for improving or refining the Programme of production control of the water treatment system in its individual sections.

APPENDIX A (to DSTU 7525:2014)

DRINKING WATER QUALITY INDICATORS AND METHODS OF THEIR CONTROL

Indicators of water composition and properties	Control methods
Microbiological indicators	
Number of bacteria in 1 cm^3 of water being tested (ZMCH) at 37 °C	[3], [4]
Number of bacteria in 1 cm^3 of water being tested (ZMC) at 22 °C	[3], [4]
Number of bacteria of the intestinal bacillus group (coliform microorganisms) in 1 dm^3 of the water being tested (BGK index)	[3], [5]
Number of thermostable intestinal bacilli (faecal coliforms – FC index) in 100 cm^3 of the water being tested	[3], [5]
Number of pathogenic microorganisms in 1 dm^3 of the water being tested	[3
Number of coliphages in 1 dm^3 of water being tested	[3
Spores of sulphite-reducing clostridia	DSTU EN 26461-1, DSTU EN 26461-2
Pseudomonas aeruginosa	DSTU ISO 10712, [6]
Virological indicators of drinking water quality	
Enteroviruses, adenoviruses, rotaviruses, reoviruses and hepatitis A virus antigen	[7
Parasitological indicators	
Number of pathogenic intestinal protozoa in 50 dm^3 of water being tested	[8
Number of intestinal helminths in 50 dm^3 of water being tested	[8]
Mycological indicators	
Microfungi	DSTU 7487. [8]
Drinking water toxicity level	
Chronic toxicity to *Ceriodaphnia affinis*	DSTU 4174
Toxicity on *Tetrahymena pyriformis*	[9
Cytotoxicity according to the leukocyte formula of the blood of Danio pepio *(Brachydanio rerio Hamilton-Buchanan)* fish	DSTU 7387
Genotoxicity on blood cells of Danio rerio *(Brachydanio rerio Hamilton-Buchanan)* fish	DSTU 7387
Radiation safety indicators	
Total volumetric activity of α-emitters (∑α-activity)	DSTU ISO 9696, (10]
Total volume activity of ß-emitters (∑β-activity)	[11
Organoleptic indicators	

Odour at 20 °C	GOST 3351, DSTU EN 1420-1
Odour when heated to 60 °C	GOST 3351, DSTU EN 1420-1
Taste and aftertaste	GOST 3351
Colour	GOST 3351, DSTU ISO 7887
Turbidity	GOST 3351, DSTU ISO 7027
Chemical quality indicators affecting the organoleptic properties of drinking water	
Inorganic components	
Hydrogen index (pH)	DSTU 4077
Dry residue (total mineralisation)	GOST 18164
Total hardness	GOST 4151, DSTU ISO 6059
Total alkalinity	DSTU ISO 9963-1, DSTU ISO 9963-2
Sulphates	GOST 4389, DSTU ISO 10304-1
Chlorides	GOST 4245. DSTU ISO 10304-1, DSTU ISO 9297
Total iron (Fe)	GOST 4011, DSTU ISO 6332
Manganese (Mn)	GOST 4974, ISO 11885, DSTU ISO 15586
Copper (Cu)	GOST 4388, DSTU ISO 11885, DSTU ISO 1 5586
Zinc (Zn)	GOST 18293. DSTU ISO 11885, DSTU ISO 15586
Calcium (Ca)	DSTU ISO 6058 DSTU ISO 11885
Magnesium (Mg)	DSTU ISO 6059, DSTU ISO 11885
Sodium (Na)	GOST 23268.6, DSTU ISO 11885
Potassium (K)	GOST 23268.7, DSTU ISO 11885
Organic components	
Petroleum products	GOST 17.1.4.01
Volatile phenols	[11
Chlorophenols	DSTU ISO 6468

Toxicological indicators	
Inorganic components	
Aluminium (Al)	GOST 18165, DSTU ISO 11885, DSTU ISO 15586
Ammonia (according to NH_4^+)	GOST 4192, DSTU ISO 6778. DSTU ISO 7150-1, DSTU ISO 5664
Barium (Ba)	DSTU ISO 11885
Beryllium (Be)	DSTU GOST 18294, DSTU ISO 15586
Boron (B)	DSTU ISO 15586
Cadmium (Cd)	DSTU ISO 11885, DSTU ISO 15586
Cobalt (Co)	DSTU ISO 11885
Arsenic (As)	GOST 4152, DSTU ISO 11885, DSTU ISO 15586
Molybdenum (Mo)	GOST 18308
Nickel (Ni)	DSTU 7150, DSTU ISO 11885
Nitrates (as NO_3^-)	GOST 18826, GOST 4192, DSTU 4078, DSTU ISO 7890-1, DSTU ISO 7890-2
Nitrites (as NO_2^-)	GOST 4192, DSTU ISO 6777
Perchlorates (ClO_4^-)	DSTU 7147
Mercury (Hg)	GOST 26927
Lead (Pb)	GOST 18293, DSTU ISO 11885, DSTU ISO 15586
Selenium (Se)	GOST 19413, DSTU ISO 15586
Strontium (Sr)	DSTU ISO 11885, GOST 23950
Antimony (Sb)	DSTU ISO 11885, DSTU ISO 15586
Thallium (TI)	DSTU 7149, DSTU ISO 15586
Fluorides (F^-)	GOST 4386, DSTU.1SO 10304-1
Total chromium (Cr)	DSTU ISO 11885, DSTU ISO 15586
Cyanides (CN^-), in particular cyanogen chloride	DSTU ISO 6703-1, DSTU ISO 6703-2, DSTU ISO 6703-3

Organic components	
Benz(a)pyrene	DSTU ISO 17993
Benzene	[13
Pesticides (total)	DSTU ISO 6468
Synthetic anionic surfactants (APAR)	DSTU ISO 7875-1
Trichloroethylene and tetrachloroethylene (sum)	DSTU ISO 10301
Carbon tetrachloride	DSTU ISO 10301
Integral indicators	
Permanganate oxidisability	GOST 23268.12
Total organic carbon	DSTU ECH 1484
Substances formed and entering drinking water during preparation	
Acrylamide	GOST 19355
Bromates	DSTU 7148
Residual chlorine dioxide	[13
Residual ozone	GOST 18301
Residual polyphosphates (PO_4^{3-})	GOST 18309
Trihalomethanes chloroform, bromoform, dibromochloromethane, bromodichloromethane (sum)	DSTU ISO 10301. [14]
Formaldehyde	[15
Residual free chlorine	GOST 18190. DSTU ISO 7393-1, DSTU ISO 7393-2, DSTU ISO 7393-3
Residual bound chlorine	GOST 18190, DSTU ISO 7393-1, DSTU ISO 7393-2, DSTU ISO 7393-3
Chlorate ion	DSTU ISO 10304-4
Chlorite ion	DSTU ISO 10304-4
Chloroform	DSTU ISO 10301, [14]
Dibromochloromethane	DSTU ISO 10301
Reagents acceptable as preservatives for drinking water	
Silver (Ad)	GOST 18293, DSTU 715D DSTU ISO 11885, DSTU ISO 15586
Carbon dioxide (CO_2)	GOST 23268 2

APPENDIX B ***(TO DSTU 7525:2014)***

FORM OF THE WATER QUALITY TEST REPORT
OF DECENTRALISED DRINKING WATER SUPPLY
AND ITS COMPLIANCE WITH THE REQUIREMENTS OF THIS STANDARD[1)]

_____
(name, details of the drinking water supply company)

Protocol No.
dated ____

Sample collection site _____
Who took the sample (surname, position, organisation)_____
Date (day, hour) of sampling_____
Time of sample arrival at the analytical laboratory_____
Date of analysis (date, time): start_____;
end_____
Address and name of laboratory_____
Permission to perform measurements_____

Test results and their compliance with the standards of this standard

Name of indicator	Units of measurement	Standard values according to the standard[2]	Measurement results	Compliance with the standards of this standard
Microbiological indicators of drinking water quality				
Number of bacteria in 1 $cm^3$of water being tested (CMU) at 37 °C	CFU/cm^3			
Number of bacteria in 1 $cm^3$of test water (ZMC) at 22 °C	CFU/cm^3			
Number of bacteria of the intestinal bacillus group (coliform microorganisms) in 1 dm^3 of the water being tested (BGK index)	CFU/dm^3			
Number of thermostable coliform bacteria (faecal coliforms –	CFU/100 cm^3			

FC index) in 100 cm^3 of the water being tested				
Number of pathogenic microorganisms in 1 dm^3 of the water being tested	CFU/dm^3			
Number of coliphages in 1 dm^3 of the water being tested	BOC/dm^3			
Spores of sulphite-reducing clostridia	Presence (number)/20 cm^3			
Pseudomonas aeruginosa	CFU/dm^3			
Virological indicators of drinking water quality				
Enteroviruses, adenoviruses, rotaviruses, reoviruses and hepatitis A virus antigen	COD/dm^3			
Parasitological indicators of drinking water quality				
Number of pathogenic intestinal protozoa in 50 dm^3 of water being tested	(Cells, cysts)/50 dm^3			
Number of intestinal helminths in 50 dm^3 of water being tested	(Cells, eggs, larvae)/50 dm^3			
Mycological indicators of drinking water quality				
Microfungi	KU0/100 cm^3			
Drinking water toxicity level				
Chronic toxicity to *Ceriodaphma affinis*	Number of dead individuals and/or reduction in the number of newborn individuals in the experiment compared to the control after (7 ±			

	1) days			
Toxicity to *Lotrahymena pyriformis*	Decrease in the growth rate of ciliates in the experiment compared to the control over a set period of time – 24 hours (short-term biotesting) or 96 hours (long-term biotesting)			
Cytotoxicity according to the leukocyte formula of the blood of Danio pepio *(Brachydanio hegio Hamilton-Buchanan)*	%			
Genotoxicity in blood cells of Danio pepio *(Brachydanio rerio Hamilton-Buchanan)* fish	%			
Radiation safety indicators for drinking water				
Total volume activity of α-emitters (∑α-activity)	Bq/dm^3			
Total volume activity of β-emitters (∑β-activity)	Bq/dm^3			
Organoleptic indicators of drinking water quality				
Odour at 20 °C	Points			
Odour when heated to 60 °C	Points			
Taste and aftertaste	Points			
Colour	Degrees			
Turbidity	NOC			
Chemical quality indicators that affect the organoleptic properties of drinking water				

Inorganic components				
Hydrogen index (pH)	Units pH			
Dry residue (total mineralisation)	mg/dm^3			
Total hardness	$mmol/dm^3$			
Total alkalinity	$mmol/dm^3$			
Sulphates	mg/dm^3			
Chlorides	mg/dm^3			
Total iron (Fe)	mg/dm^3			
Manganese (Mn)	mg/dm^3			
Copper (Cu)	mg/dm^3			
Zinc (Zn)	mg/dm^3			
Calcium (Ca)	mg/dm^3			
Magnesium (Mg)	mg/dm^3			
Sodium (Na)	mg/dm^3			
Potassium (K)	mg/dm^3			
Organic components				
Petroleum products	mg/dm^3			
Volatile phenols	mg/dm^3			
Chlorophenols	mg/dm^3			
Toxicological indicators of the safety of the chemical composition of drinking water				
Inorganic components				
Aluminium (Al)	mg/dm^3			
Ammonia (as NH_4^+)	mg/dm^3			
Barium (Ba)	mg/dm^3			
Beryllium (Be)	mg/dm^3			
Boron (B)	mg/dm^3			
Cadmium (Cd)	mg/dm^3			
Cobalt (Co)	mg/dm^3			
Arsenic (As)	mg/dm^3			
Molybdenum (Mo)	mg/dm^3			
Nickel (Ni)	mg/dm^3			
Nitrates (as NO_3^-)	mg/dm^3			
Nitrites (as NO_2^-)	mg/dm^3			
Perchlorates (ClO_4^-)	mg/dm^3			
Mercury (Hg)	mg/dm^3			
Lead (Pb)	mg/dm^3			
Selenium (Se)	mg/dm^3			
Strontium (Sr)	mg/dm^3			
Antimony (Sb)	mg/dm^3			
Thallium (TI)	mg/dm^3			
Fluorides (F^-)	mg/dm^3			

Total chromium (Cr)	mg/dm^3			
Cyanides (CN^-), in particular cyanogen chloride	mg/dm^3			
Organic components				
Benz(a)pyrene	mg/dm^3			
Benzene	mg/dm^3			
Pesticides (total)	mg/dm^3			
Synthetic anionic surfactants (APAR)	mg/dm^3			
Trichlorethylene and tetrachlorethylene (sum)	mg/dm^3			
Carbon tetrachloride	mg/dm^3			
Integral indicators				
Permanganate oxidisability	mg O/dm^3			
Total organic carbon	mg O/dm^3			
Substances formed and entering drinking water during water treatment				
Acrylamide	mg/dm^3			
Bromates	mg/dm^3			
Chlorine dioxide residual	mg/dm^3			
Residual ozone	mg/dm^3			
Residual polyphosphates (PO_4^{3-})	mg/dm^3			
Trihalomethanes: chloroform, bromoform, dibromochloromethane, bromodichloromethane (total)	mg/dm^3			
Formaldehyde	mg/dm^3			
Residual free chlorine	mg/dm^3			
Residual bound chlorine	mg/dm^3			
Chlorate ion	mg/dm^3			
Chlorite ion	mg/dm^3			
Chloroform	mg/dm^3			
Dibromochloromethane	mg/dm^3			

Reagents permitted as preservatives for drinking water				
Silver (Ag)	mg/dm^3			
Carbon dioxide (CO_2)	%			

[1)] The form of the protocol for testing the quality of drinking water and issuing conclusions on its compliance with the requirements of this standard is based on the form of the Water Testing Protocol No. 325/0, approved by Order of the Ministry of Health of Ukraine No. 160 dated 11 July 2000.

[2)] The values of the standards are given in Tables 6.1 – 6.4, 6.6 – 6.10 of this standard.

Scientific and technical documentation on research methods _____

_____

_____

_____

_____

Signature of the person who conducted the research _____
(position, full name)

Conclusions of officials on the compliance of drinking water quality with the criteria of this standard

_____

_____

_____

_____

_____

_____

Seal

APPENDIX 2

RULES FOR ACCEPTING
WASTEWATER INTO THE CENTRALISED WASTEWATER DISPOSAL SYSTEM OF THE CITY OF KYIV

I. General provisions

1. The rules for accepting wastewater into the centralised water disposal system of the city of Kyiv (hereinafter referred to as the Rules) have been developed on the basis of the Rules for accepting wastewater into centralised water disposal systems (hereinafter referred to as the national Rules), approved by Order of the Ministry of Regional Development, Construction and Housing and Communal Services of Ukraine dated 1 December 2017 No. 316, registered with the Ministry of Justice of Ukraine on 15 January 2018 under No. 56/31508, and taking into account local features of wastewater acceptance and treatment, determine the permissible concentrations of pollutants that can be discharged into the centralised wastewater disposal system, as well as issues related to the sampling of wastewater for analysis and the sampling procedure.

2. These Rules apply to business entities engaged in centralized water disposal (discharge and/or treatment of wastewater) (hereinafter referred to as the contractor), legal entities regardless of their form of ownership and departmental affiliation, individual entrepreneurs, individuals who carry out independent professional activities and are registered as self-employed persons with the controlling authorities in accordance with the Tax Code of Ukraine, who use drinking water for the production of goods and the provision of services and discharge wastewater into centralised water disposal systems either directly or indirectly into the treatment facilities of the centralised water disposal system (hereinafter referred to as consumers).

3. The terms used in these Rules have the following meanings:

facility inspection report – a document drawn up based on the results of an inspection of the consumer's facility, local drainage networks and treatment facilities by authorised representatives of the contractor;

normatively clean water – water that is discharged into the centralised water disposal system after cooling the technological equipment;

calculation period – the period specified in the calculation issued by the contractor, for which the consumer is charged for water supply and sanitation services;

population equivalent – a numerical indicator of the load of wastewater with organic substances subject to biological decomposition, with a five-day biochemical oxygen demand of 60 grams of oxygen per person per day;

consumer – a legal entity regardless of the form of ownership and departmental affiliation, an individual entrepreneur, a natural person who carries out independent professional activities and is registered as a self-employed person with the regulatory authorities in accordance with the Tax Code of Ukraine, who uses drinking water for the production of goods and the provision of services and discharges wastewater into centralised wastewater disposal systems either directly

or indirectly into the treatment facilities of the centralised wastewater disposal system.

Other terms used in these Rules are used in the meanings given in the Water Code of Ukraine, the Law of Ukraine "On Water Disposal and Wastewater Treatment", "On Housing and Communal Services", "On Consumer Protection" and the Rules for the use of centralized municipal water supply and wastewater disposal systems in populated areas of Ukraine, approved by Order of the Ministry of Housing and Communal Services of Ukraine No. 190 of 27 June 2008, registered with the Ministry of Justice of Ukraine on 7 October 2008 under No. 936/15627 (hereinafter referred to as the Rules of Use), Rules for the acceptance of wastewater into centralised wastewater disposal systems and the Procedure for determining the amount of fees charged for excessive wastewater discharges into centralised wastewater disposal systems, approved by Order of the Ministry of Regional Development, Construction and Housing and Communal Services of Ukraine No. 316 dated 1 December 2017, registered with the Ministry of Justice of Ukraine on 15 January 2018 under No. 56/31508, No. 57/31509, as amended by Order of the Ministry of Community and Territorial Development of Ukraine No. 286 dated 9 November 2021.

4. These Rules are aimed at preventing violations in the operation of wastewater disposal and treatment systems, improving the safety of such systems, ensuring the protection of the environment from pollution by wastewater discharges, and are mandatory for contractors and consumers.

5. Contractors shall establish requirements for each specific consumer for the discharge of wastewater into the centralised drainage system on the basis of the national Rules and these Rules.

6. The contractor shall conclude a contract with the consumer, provided that the drainage network and treatment facilities of the centralised drainage system have reserve capacity. The contractor shall accept the consumer's wastewater into the centralised drainage system, provided that the quality indicators of the consumer's wastewater meet the requirements of these Rules.

7. Each consumer shall discharge wastewater into the centralised wastewater disposal system through a separate outlet with the mandatory installation of a control well located in a place agreed with the contractor.

The combination of wastewater outlets from several consumers may only be carried out after the control well at the wastewater outlet of each consumer.

The discharge of wastewater by a sub-consumer using the consumer's drainage network does not constitute a combination of wastewater outlets from several consumers.

8. Wastewater transported from consumers by sewage trucks shall be **accepted** into the centralised wastewater drainage system only through the contractors' discharge stations (points), and in their absence, the place of discharge of such wastewater shall be determined in the contract.

The conditions for accepting and paying for the treatment of such wastewater are determined by these Rules.

9. Uniform permissible concentrations of pollutants shall be established for

all consumers discharging wastewater into the centralised wastewater disposal system.

10. The acceptance of consumers' wastewater into the centralised water disposal system or directly to the treatment facilities of the centralised water disposal system shall be carried out exclusively under contracts.

11. The discharge of melt water from snow melting chambers or snow dumps into the centralised water disposal system shall be permitted only in the event of a justified calculation of such a need, taking into account the throughput capacity of the water disposal collectors and the installation of local treatment facilities in accordance with the requirements of DBN V.2.5-75:2013 "Sewerage. External networks and structures".

II. Principles of uninterrupted operation of centralised drainage systems during the reception of consumer wastewater

1. Contractors:

1). Ensure the reception, discharge and treatment of wastewater within the calculated design parameters of the centralised wastewater disposal system and treatment facilities of the centralised wastewater disposal system in compliance with the requirements of the Rules for the protection of surface waters from pollution by return waters, approved by Resolution of the Cabinet of Ministers of Ukraine No. 465 of 25 March 1999;

2). Establish requirements for each specific consumer for the discharge of wastewater into the centralised water disposal system, taking into account the throughput capacity and design parameters of such a system, taking into account the requirements of these Rules;

3). Conduct surveys of local treatment facilities and consumer drainage networks, require consumers to provide information and documents regarding the specified networks and facilities that are on the consumers' balance sheet, their technical condition, including documents confirming the restoration of the throughput capacity of pipelines and collectors, chemical reagents used by consumers and causing pollution in wastewater (certificates, lists, projects), the removal and disposal of wastewater sludge, measures taken to ensure the quality and discharge regime of wastewater in accordance with the requirements of these Rules, which may require the provision of other information and documentation that is not of a permissive nature and relates to the discharge of wastewater at consumer facilities;

Based on the results of the inspections, an inspection report is drawn up, which is signed by authorised representatives of the contractor and the consumer. If the consumer's representative refuses to sign the facility inspection report, the contractor's representatives shall make a corresponding note in the report and send one copy to the consumer within five working days from the date of its compilation in order to eliminate the violations specified therein within the time limit set in the report;

4). Control the quality, quantity and mode of wastewater discharge by consumers;

5). Carry out selective control of the efficiency of local treatment facilities and require consumers to adjust or reconstruct them to comply with the requirements of these Rules;

6). Carry out unannounced (at any time of the day) sampling of wastewater discharged in accordance with these Rules, without prior agreement with consumers;

7). Disconnect consumers from the wastewater disposal system immediately after a verbal warning in the event of a threat of failure of the centralised wastewater disposal systems, violation of the technological mode of operation of the treatment facilities of the centralised water drainage system and in the event of unauthorised connection by the consumer to the centralised water drainage systems and/or discharge of wastewater into the centralised water drainage systems of the contractor in the absence of a valid contract for centralised water drainage. In this case, the contractor shall not be liable for the losses of such consumers. Connection to wastewater systems is carried out at the expense of the consumer after the circumstances that caused the disconnection have been eliminated and the contractor has been compensated for any losses (if any);

8). In the event of violations by consumers of the conditions for wastewater discharge, the requirements of these Rules and the terms of the contract concluded with the contractor, require their elimination within the time limits set by the contractor and take measures of influence provided for by the contract and these Rules;

9). Require consumers whose facilities are located in residential buildings and have wastewater of technological or non-domestic origin to ensure the drainage of wastewater from the facility through a separately equipped drainage outlet with a control well.

10). Require consumers, in accordance with the established procedure, to develop measures to bring the quality of wastewater to the established permissible concentrations of pollutants (hereinafter referred to as PC);

11). Ensure systematic control over the operation of municipal treatment facilities of the centralised wastewater disposal system.

In the event of an emergency, immediately notify the territorial body of the central executive authority that exercises state supervision (control) over compliance with environmental legislation, indicating the reasons for these violations;

12). In the event of repeated, recorded discharge of wastewater exceeding the permissible concentrations of pollutants, the contractor shall require the consumer discharging such wastewater of technological origin to construct a centralised wastewater disposal system or reconstruct local treatment facilities (hereinafter referred to as LOS) and to conclude an agreement with the contractor on the acceptance of excessively polluted wastewater in accordance with these Rules.

2. Consumers:

1). Receive and comply with the requirements for the discharge of wastewater into the centralised water disposal system, require sub-consumers to comply with the provisions of these Rules;

2). Systematically monitor the quantity and quality of wastewater discharged by them into centralised water disposal systems in accordance with the sampling schedule agreed with the contractor, provide the contractor with information on the volume and quality of wastewater discharged by consumers into centralised water disposal systems;

3). At the request of the contractor, carry out preliminary treatment of polluted wastewater at local treatment facilities by the deadline specified by the contractor, with mandatory disposal or removal of the resulting sludge, if the consumers' wastewater does not meet the requirements of these Rules and the terms of the contract concluded with the contractor;

4). In the event of changes in their water disposal (transfer of water disposal buildings and networks to other owners/users, changes in technological processes or changes of 30% or more in previous water disposal volumes, construction work on the territory of the facility (in cases where it affects or may affect the consumer's compliance with the discharge requirements issued by the contractor), connection of a sub-consumer, etc.), they shall notify the contractor within 7 days of such changes and, in accordance with the established procedure, obtain from the contractor the technical conditions for water supply and drainage of the facility and the requirements for wastewater discharge, as well as make the appropriate changes to the contract;

5). Conclude a new contract with the contractor in the event of a change of ownership of the facility;

6). Provide the contractor's employees with the necessary information about their wastewater disposal system and free access to it, as well as assistance in sampling consumers' wastewater, studying their discharge regime, inspecting consumers' wastewater disposal systems and local treatment facilities;

7). Appoint at least two representatives authorised to represent the consumer during the sampling of wastewater, notify the contractor in writing within three days and ensure the presence of an authorised representative directly during the sampling of wastewater by the contractor;

8). Participate in the elimination of accidents and replacement of emergency drainage networks using their own resources and means, as well as in the reimbursement of capital costs for the restoration of the contractor's centralised drainage system in the event of deterioration of its technical condition and emergency damage through the fault of the consumer;

9). Verify the calculations of the excess of the maximum permissible concentration of pollutants in wastewater discharged by them into the centralised drainage system, performed by the contractor, and in case of disagreement, request their revision.

10). Submit a document confirming the implementation and restoration of the throughput capacity of pipelines and collectors using technical means at least

once a year, and consumers – business entities whose activities are related to public catering services – at least twice a year. In the event of clogging of the drainage networks with pollutants that lead to a reduction in the throughput capacity of the municipal drainage network, immediately restore the throughput capacity of pipelines and collectors using technical means;

11). Pay the contractor's invoices for the discharge of wastewater exceeding the permissible levels of pollutants;

12). Notify the contractor in writing of the elimination of violations within the time limits specified in the facility inspection reports;

13). Maintain the consumer's inspection wells in proper condition, fence them off if necessary and ensure access to them (clear wells of snow, ice and debris, do not place construction materials on them, do not block them with vehicles and machinery);

14). Comply with the requirements of DBN V 2.5-64:2012 "Internal water supply and sewerage", including installing grease traps (grease separators) before discharge into the municipal drainage system in the specified cases.

III. Basic requirements for the acceptance/discharge of wastewater into the centralised drainage system

1. Connection of consumers to the centralised drainage system:

1). Connection of consumers to the centralised water drainage systems of the city of Kyiv is carried out in accordance with the procedure established by law, including taking into account the Rules of Use.

2). In the cases provided for in Article 3 of the Law of Ukraine "On Environmental Impact Assessment", an environmental impact assessment is mandatory in the process of making decisions on the implementation of planned activities.

3). When the contractor makes a decision on the acceptance of wastewater into the centralised water disposal system in relation to consumers who are already operating and those whose facilities are being reconstructed or built, the following shall be taken into account:

the introduction of technological processes that will reduce the amount of pollutants in wastewater;

mandatory installation of recycled water supply systems (except for consumers whose facilities discharge domestic wastewater);

preliminary treatment of wastewater at local treatment facilities (if the consumer carries out production processes specified in Appendix 1 to these Rules);

joint preliminary treatment of wastewater from such a facility with wastewater from other facilities at treatment facilities shared by several consumers of the centralised water disposal system.

4). During the reconstruction or construction of a facility, the consumer is obliged to notify the contractor in writing of the performance of these works and the terms of their completion, obtain technical conditions, develop and submit for

review and storage to the contractor the project documentation. Upon completion of the works, provide the contractor with an act of demarcation of the balance sheet ownership of the drainage networks and the operational responsibility of the parties.

2. Requirements for wastewater discharge.

1). The consumer shall obtain the requirements for wastewater discharge from the contractor (Appendix 2).

2). To obtain the requirements for wastewater discharge, the consumer shall apply to the contractor with the following documents:

- a letter in any form regarding the need to obtain/extend the validity period of the discharge requirements. In case of extension of the validity period of the wastewater discharge requirements, the letter shall be submitted one month before the expiry of the validity period of the received wastewater discharge requirements;
- a master plan of the consumer's facility on a scale of 1:500 with the drainage network marked, signed by an authorised representative of the consumer, in two copies;
- general information about the consumer (Appendix 3);
- a normative calculation of water consumption and drainage at the consumer's facility;
- a balance of water consumption and water disposal at the consumer's facility (Appendix 4);
- a breakdown of the volumes of industrial and domestic wastewater (Appendix 5);
- an act of demarcation of the balance sheet ownership of the consumer's wastewater disposal networks (drawn up by the consumer together with the contractor);
- technical characteristics of VOCs and/or treatment facilities of the centralised wastewater disposal system at the consumer's facility;
- list of sub-consumers;
- document on the disposal and storage of sludge from the treatment facility of the centralised water disposal system.

3. Within one month of receiving the full set of documents specified in subparagraph 2 of paragraph 2 of Section III of these Rules, the contractor shall review them and issue requirements for wastewater discharge.

4. The processing of personal data received from the consumer shall be carried out by the contractor in accordance with the Law of Ukraine "On the Protection of Personal Data".

5. Requirements for wastewater discharge shall be issued for a period of one year.

6. If the consumer evades receiving the requirements for wastewater discharge within three months from the date of conclusion of the contract for the provision of centralised water supply and centralised wastewater disposal

services, the contractor shall send the consumer a warning about their violation of the requirements of the national Rules and these Rules.

If the consumer continues to discharge wastewater into the centralised wastewater disposal system without receiving the wastewater discharge requirements, the discharge fee shall be determined in accordance with paragraph 8 of Section II of the Procedure for determining the amount of the fee charged for excessive wastewater discharges into centralised wastewater disposal systems, approved by Order of the Ministry of Regional Development, Construction and Housing and Communal Services of Ukraine No. 316 of 1 December 2017, registered with the Ministry of Justice of Ukraine on 15 January 2018 under No. 57/31509.

7. If the consumer declares that there have been no changes in their water disposal, the conditions of these Rules are fulfilled, and the inspection report does not establish the contrary, the requirements for wastewater discharge are extended for an equivalent period. The consumer must submit a written request to the contractor for the extension of the requirements for wastewater discharge one month before the expiry of their validity.

8. Conditions for discharging wastewater into the Kyiv city drainage system, obtained by consumers in accordance with the established procedure prior to the entry into force of these Rules, shall remain in force for the period specified therein.

IV. General requirements for the composition and properties of wastewater discharged into centralised drainage systems

1. The centralised drainage system accepts wastewater from consumers that does not disrupt the operation of drainage networks and treatment facilities, their safe operation and can be neutralised at the treatment plant of the centralised water disposal system in accordance with the requirements of the Rules for the Protection of Surface Waters from Pollution by Return Waters, approved by Resolution of the Cabinet of Ministers of Ukraine No. 465 of 25 March 1999.

2. Wastewater accepted into the centralised wastewater disposal system must not:

1) contain combustible impurities and dissolved gaseous substances capable of forming explosive mixtures;

2) contain substances that can clog pipes, wells, grates or settle on their surfaces (debris, soil, abrasive powders and other coarse suspensions, gypsum, lime, sand, metal and plastic shavings, fats, resins, fuel oil, brewer's grains, baker's yeast, etc.);

3) contain only inorganic substances or substances that are not subject to biological destruction;

4) contain substances for which no maximum permissible concentrations (hereinafter referred to as MPC) have been established for water bodies or toxic substances that prevent biological treatment of wastewater, as well as substances

for which no analytical control methods have been developed;

5) contain dangerous bacterial, viral, toxic and radioactive contaminants;

6) contain biologically rigid synthetic surfactants (hereinafter referred to as SUR), the level of primary biological decomposition of which is less than 80%;

7) have a temperature above 40°C;

8) have a pH below 6.5 or above 9.0;

9) have a chemical oxygen demand (hereinafter referred to as COD) higher than the biological oxygen demand over 5 days (hereinafter referred to as BOC_5) by more than 2.5 times;

10) have a BOC that exceeds that specified in the design of the centralised water disposal system treatment facility for the relevant settlement;

11) create conditions that are harmful to the health of personnel servicing centralised water disposal systems;

12) make it impossible to utilise sewage sludge using methods that are safe for the environment;

13) contain pollutants in excess of the permissible concentrations established by these Rules.

3. If the consumer's facilities carry out production processes included in the list of production processes for which the consumer must have a LOS for preliminary treatment of wastewater before its discharge into centralised wastewater disposal and treatment systems (Appendix 1), as well as in the case of systematic discharge of excessive pollutants, the discharge of wastewater into centralised water disposal systems without prior treatment at local treatment facilities is not permitted.

The consumer's local treatment facilities must comply with the technical conditions issued by the contractor in accordance with the Rules of Use.

4. It is prohibited to discharge wastewater containing pollutants into the centralised water disposal system without prior treatment and disinfection at local treatment facilities with mandatory disposal or burial of the resulting sludge. The list of pollutants that are prohibited from being discharged into the centralised water disposal system is provided in Appendix 6 to these Rules.

It is prohibited to discharge wastewater from atmospheric precipitation into centralised wastewater disposal systems if there is a separate centralised storm water drainage system.

5. If the quantitative and qualitative indicators of the consumer's wastewater change significantly during the day and the concentration of pollutants exceeds the MPC, the consumer must install special averaging tanks and devices that ensure a uniform discharge of wastewater throughout the day.

6. If the consumer is unable to comply with the requirements of these Rules, including paragraph 3 of this section for certain indicators, they shall submit an application to the contractor with a justification for the acceptance of excessively polluted wastewater, indicating its concentration, and undertake to take measures to bring the quality and discharge regime into line with the requirements of these Rules within the period specified in the contract.

The contractor shall consider the submitted application within 15and shall

conclude a separate contract with the consumer for the acceptance of excessively polluted wastewater if the existing centralised water disposal system at the treatment plant of the wastewater treatment technology provider is capable of removing the specified pollution in accordance with the maximum permissible discharge (GDS) established for the contractor.

The agreement on the acceptance of excessively polluted wastewater shall specify the temporarily agreed concentrations of pollutants and the amount of additional payment for the acceptance of excessively polluted wastewater, which shall be within 60-80% of the payment established in accordance with Section II of the Procedure for determining the amount of payment levied for excessive discharges of wastewater into centralised water disposal systems, approved by Order of the Ministry of Regional Development, Construction and Housing and Communal Services of Ukraine No. 316 of 1 December 2017, registered with the Ministry of Justice of Ukraine on 15 January 2018 under No. 57/31508, (hereinafter referred to as the Procedure), and the period necessary to complete the construction and commissioning of local treatment facilities (if such commissioning is provided for by the Law of Ukraine "On Regulation of Urban Development"), which must be justified in accordance with the developed project and may not exceed five years from the date of conclusion of the contract.

If the actual concentration of any indicator exceeds that specified in the contract for the acceptance of excessively polluted wastewater, the consumer shall pay an additional fee for wastewater disposal services with a multiplier coefficient determined in accordance with the Procedure and these Rules, but instead of the established DK for calculation, the temporarily agreed concentrations specified in the contract for the acceptance of excessively polluted wastewater shall be applied.

7. The sub-consumer's wastewater is part of the consumer's wastewater.

8. If the established maximum permissible concentrations of pollutants are exceeded and a violation specified in paragraph 7 of Section VII of these Rules is detected, the contractor shall issue the corresponding invoices to consumers in accordance with the established procedure.

9. Determination of the population equivalent of the city of Kyiv.

In accordance with the Law of Ukraine "On Water Drainage and Wastewater Treatment" and Order No. 6 of the Ministry of Ecology and Natural Resources of Ukraine dated 14 January 2019 "On Approval of the Procedure for Determining the Population Equivalent of a Settlement and the Criteria for Determining Vulnerable and Less Vulnerable Areas", registered with the Ministry of Justice of Ukraine on 5 February 2019 under No. 125/33096, the population equivalent of the city of Kyiv is 5,720,902.

V. Determination of the maximum permissible concentration of pollutants in consumers' wastewater

1. The contractor determines the maximum permissible concentration of pollutants in consumers' wastewater as the smallest of the following four values:

1) the maximum permissible concentration of a pollutant in the sewage system (at the consumer's sewage outlet);

2) the maximum permissible concentration of a pollutant in biological treatment facilities (at the inlet to these facilities);

3) the limits for the discharge of pollutants specified in the special water use permit issued to the contractor in accordance with Article 49 of the Water Code of Ukraine;

4) the permissible content of heavy metals in wastewater sludge that can be used as organic fertilisers in accordance with Appendix 7 to these Rules.

The calculation of the MC of pollutants in consumers' wastewater is carried out for each treatment facility of the contractor's centralised wastewater disposal system or for each of the wastewater collectors that discharge wastewater to these treatment facilities.

2. When determining the MC of a pollutant in wastewater, the MC in the wastewater collection system shall be taken in accordance with the requirements for the composition and properties of wastewater discharged into the centralised wastewater collection system for its safe disposal and treatment at the treatment facilities of the centralised wastewater collection system, as set out in Annex 8 to these Rules.

3. When a consumer discharges pollutants other than those specified in Appendix 8 to these Rules, the MC of these pollutants shall be determined in accordance with Appendix 9 to these Rules and shall be specified in the requirements for wastewater discharge.

4. When determining the MC of the j-th pollutant in wastewater according to the MC in biological treatment facilities, the calculation shall be performed using the formula

$$ДК_j^{bo} = \frac{(C_j - C_j^{gp}) \times Q}{\sum_{i=1}^{n} Q_i} + C_j^{gp}, \text{ (g/m}^3\text{)},$$

where: $ДК_j^{bo}$ is the concentration of pollutant j in wastewater before biological treatment facilities;

Cj - DC of the j-th pollutant in biological treatment facilities, (g/m^3) (accepted according to the operating regulations of the centralized wastewater disposal system treatment facilities of the contractor or taking into account the permissible values of wastewater quality indicators and the efficiency of pollutant removal at biological treatment facilities in accordance with Appendix 9 to these Rules);

Q - average daily wastewater flow at the inlet to the treatment facility of the centralised water disposal system, (m^3/day);

$\sum^{n}_{i=1} Q_i$ - average daily wastewater flow of consumers that may contain this pollutant, (m^3/day);

C_j^{gp}- concentration of the j-th pollutant in domestic wastewater, (g/m^3) (taken from the actual average data of the contractor's operating services. In the

absence of such data, the following is accepted: for ammonium nitrogen - 20 g/m³; total iron - 2 g/m³; fats – 30 g/m³; SPAR - 5 g/m³; chlorides - an additional 50 g/m³ to the content in the water supply source; phosphates - 10 (g/m(3)); for other substances regulated by the State Sanitary Norms and Rules "Hygienic Requirements for Drinking Water Intended for Human Consumption" (DSanPiN 2.2.4-171-10), approved by Order of the Ministry of Health of Ukraine No. 400 of 12 May 2010, registered with the Ministry of Justice of Ukraine on 1 July 2010 under No. 452/17747, - for the average annual content in tap water).

5. In the event of the presence in wastewater entering the treatment facility of the centralized wastewater disposal system of a settlement several pollutants of hazard classes 1 and 2 specified in Appendix 9 to these Rules, which are regulated by sanitary and toxicological criteria, it is necessary to reduce the MC of each of these substances by the number of times that such substances are present in the wastewater.

6. The DC of the j-th pollutant in terms of the total limit for its discharge into a water body (Lzag, t/year) is calculated using the formula:

$$ДК_j^{zl} = \frac{(L_{zag} - L_{gp}) \times 10^6}{365 \times (1 - K_j) \sum_{i=1}^{n} Q_i}, \text{ (g/m}^3\text{)}$$

where:$ДК_j^{zl}$ - the DC of the j-th pollutant in wastewater based on the total limit for its discharge

$$L_{gp} = \frac{365 \times C_j^{gp} \times Q_{gp} \times (1 - K_j)}{10^6}, \text{ (t/year) –}$$

the share of the limit attributable to domestic wastewater from the settlement;

365 – number of days in a year;

Q_{gp} – average daily consumption of domestic wastewater at the inlet to the treatment plant of the centralised water disposal system, (m³/day);

$\sum^{n}_{i=1} Q_i$ – average daily consumption of wastewater by consumers that may contain this pollutant, m³ /day;

C_j^{gp} – concentration of the j-th pollutant in domestic wastewater, (g/m³);

K_j – coefficient of efficiency of removal of the j-th pollutant at the treatment facility of the contractor's centralised wastewater disposal system. The value of the coefficient Kj is taken according to actual data for specific treatment facilities, and in their absence - according to Appendix 9 to these Rules.

7. The DC of the j-th pollutant for the permissible content of heavy metals in wastewater sludge at the level permitted for sludge that can be used as organic fertilisers is calculated using the formula:

$$ДК_{jvm} = \frac{(C_{jvm} - C_{jvm}^{gp}) \times Q}{\sum_{i=1}^{n} Q_i} + C_{jvm}^{gp}, \text{ (g/m}^3\text{)},$$

where: DCjvm – DC of the j-th pollutant in wastewater for the permissible content of heavy metals in wastewater sludge;

C_{jvm} – permissible concentration of the j-th heavy metal at the inlet to the treatment plant of the centralised water disposal system – is calculated using the formula:

$$C_{jvm} = \frac{(q_1 \times K_1 + q_2 \times K_2) \times C^{oc}_{jvm}}{K_j \times Q} \text{ (g/m}^3\text{);}$$

q_1 – amount of raw sludge retained in primary clarifiers, t/day;

q_2 – amount of activated sludge retained in secondary clarifiers, t/day;

K_1 – conversion factor for raw sludge from primary clarifiers to dry matter,

$$K_1 = \frac{100 - W_1}{100},$$

where: W_1 – moisture content of raw sludge, %;

K_2 – conversion factor for excess active sludge from secondary clarifiers to dry matter,

$$K_2 = \frac{100 - W_2}{100},$$

where: W_2 - moisture content of excess active sludge, %;

C^{oc}_{jvm} – permissible content of j-th heavy metal in sediments, g/t of dry matter. Accepted according to the data in Appendix 7 to these Rules;

K_j – coefficient of efficiency of removal of the j-th heavy metal at the treatment facility of the centralised water disposal system.
Accepted based on the average actual operating data of the treatment plant of the centralised water disposal system, and in their absence, based on the data specified in Appendix 7 to these Rules;

Q – average daily wastewater flow at the inlet to the treatment plant of the centralised water disposal system, (m^3/day);

$\sum^{n}_{i=1} Q_i$ – average daily wastewater flow of consumers that may contain this pollution, (m^3/day);

Cgp_{jvm} – concentration of the j-th heavy metal in domestic wastewater, g/m^3. It is taken as the average annual content in the tap water of the respective settlement.

VI. Measures to be taken in case of violation of the requirements for wastewater discharge into centralised water disposal systems

1. Failure to comply with these Rules and other regulatory and legal acts governing water disposal issues shall result in the application of measures of influence to contractors and consumers, as provided for by the legislation of Ukraine and the terms of the relevant contracts.

2. In the event of failure by consumers to comply with these Rules regarding the quality and regime of wastewater discharge, the consumer's facility may be disconnected from the centralised water disposal system after a written warning from the contractor at least 5 days in advance.

Consumers who carry out the production processes specified in Appendix

1 to these Rules and have concluded an agreement with the contractor on the acceptance of excessively polluted wastewater, which provides for the construction of local treatment facilities, cannot be disconnected from the centralised wastewater disposal system on the grounds of not having treatment facilities during the term of the agreement, provided that these consumers comply with the terms of such an agreement in good faith and in a timely manner.

3. In the event of monetary penalties being imposed on the contractor for exceeding the limits for discharges into water bodies or other violations of environmental legislation, the contractor may demand reimbursement of these amounts from the consumers responsible for the violation on a recourse basis.

4. If it is necessary to relocate emergency or replace destroyed networks and structures of the centralised water disposal system due to the aggressive impact of the consumer's wastewater, the estimated cost of these works (total capital investment) Kzag (thousand UAH) shall be distributed among consumers who discharged wastewater in violation of these Rules and through whose fault the corresponding damage occurred, according to the formula:

$$K_i = \frac{Q_i \times Z_i}{\sum_{i=1}^{n} Q_i \times Z_i} \times K_{zag}$$

where: K_i – compensation for damages caused by the i-th consumer for the restoration of destroyed networks and structures, thousand UAH;

Q_i – average daily wastewater discharge by the i-th consumer, m^3 /day;

Z_i – the amount of payments for the discharge of excessive pollutants with aggressive properties, collected by the contractor over the last three years from the i-th consumer, thousand UAH.

5. In the event of clogging of the sewage networks with consumer wastewater pollution (fats, sediments, coarse-grained suspensions), which lead to a reduction in the throughput capacity of the contractor's sewage network, consumers shall reimburse the costs, which must be documented by the contractor, for carrying out work to restore the throughput capacity of pipelines and collectors.

6. If it is impossible to dispose of sediments and sludge due to the increased content of heavy metals, toxic substances, etc., and it is necessary to place sediments and sludge in special landfills, the estimated cost of these works (including environmental tax) shall be distributed among consumers who are responsible for the contamination of sediments and sludge with toxic substances. The estimated cost of these works for a specific consumer is calculated using the following formula:

$$B_i = \frac{M_i}{\sum_{i=1}^{n} M_i} \times B_{zag}$$

where: B_i – the share of the cost of works on the disposal of sludge and silt to be reimbursed by the i-th consumer;

B_{zag} – total estimated cost of works on disposal of sediments and sludge, thousand UAH;

M_i – discharges of pollutants by the i-th consumer, which require disposal of sediments only by burial in special landfills, (t);

$\sum_{i=1}^{n} M_i$ – total discharges of pollutants requiring disposal of sediments only by burial in special landfills (t).

7. The consumer shall not have the right to discharge wastewater without establishing requirements for wastewater discharge. For the discharge of wastewater without requirements for wastewater discharge or after the expiry of their validity, the fee for wastewater discharge shall be determined in accordance with paragraph 8 of Section II of the Procedure.

8. If the consumer fails to comply with the requirements of the Rules or the terms of the contract for the provision of centralised water supply and/or centralised water disposal services, the contractor shall send its representative to inspect the consumer's facility, based on the results of which an inspection report shall be drawn up in accordance with subparagraph 3 of paragraph 1 of Section II of these Rules with a requirement to eliminate the identified violations within the period specified in the report. If the consumer fails to comply with the requirements specified in the report, the contractor shall have the right (after a written warning 7 days in advance) to suspend the requirements for wastewater discharge during their period of validity by sending a written notice to the consumer.

9. In case of violations of these Rules, the contractor shall inform the relevant authorities about the consumers who committed these violations.

VII. Procedure for monitoring the discharge of wastewater into centralised water disposal systems

1. Consumers shall control the quantity and quality of wastewater they discharge into the centralised water disposal system or directly to the treatment facilities of the centralised water disposal system of the contractors. The list of pollutants to be analysed is specified in Appendices 8 and 9 to these Rules.

If there are local treatment facilities, consumers shall monitor the quantity and quality of wastewater entering them, treated wastewater, and take into account the volume of sludge removed from wastewater. The removal and disposal of sludge shall be documented (acts, waybills, invoices), which shall be kept by consumers for at least three years.

The locations and frequency of sampling by consumers shall be agreed with the contractor.

The results of wastewater analyses and measurements of wastewater consumption shall be recorded in work logs, which shall be kept by consumers indefinitely.

Consumers shall systematically, within the time limits specified in these Rules (in accordance with the sampling schedule specified in subparagraph 2 of paragraph 2 of Section II of these Rules), provide the contractor with information on the volume and qualitative composition of wastewater that they discharge into the centralised wastewater disposal system or directly to the treatment facilities

of the contractors' centralised wastewater disposal system.

Consumers are required to have and regularly update technical documentation describing the condition of their water supply and drainage systems, namely: information about the consumer's water supply and drainage systems, characteristics of their technical parameters and actual condition, graphic material (master plan (topographic plan) with marked water supply and drainage networks and the location of the control well, normative calculation of the consumer's water consumption and drainage, technological drawings of pumping stations, plan and diagram of local treatment facilities and the availability of metering devices, information about the categories of the consumer's wastewater (industrial, domestic, surface, etc.), characteristics of the quality of wastewater discharged into the centralised wastewater disposal system, except for those that are of a permissive nature.

2. Consumers must immediately inform the contractor of all cases of deterioration in wastewater quality, emergency and sudden discharges of pollutants, and emergency repair work.

3. Consumers who discharge wastewater into the centralised water disposal system or directly to the treatment facilities of the contractor's centralised water disposal system must ensure that the contractor can monitor the discharge of wastewater at any time of the day.

4. To determine the content of pollutants in consumers' wastewater, data from the contractor's laboratory shall be used, and in its absence, data from other laboratories operating in this field in accordance with the requirements of the Law of Ukraine "On Metrology and Metrological Activity" shall be used.

5. When analysing wastewater samples taken from consumers, measuring equipment shall be used that has been verified or calibrated by authorised bodies in accordance with the requirements of Articles 17 and 27 of the Law of Ukraine "On Metrology and Metrological Activity".

6. The selection of control samples of consumers' wastewater shall be carried out by an authorised representative of the contractor, which shall be recorded in a special logbook – the act of sampling consumers' wastewater (Appendix 10) (hereinafter referred to as the logbook – act) or the act of sampling wastewater (return water) (Appendix 11) (hereinafter referred to as the sampling report), which shall be signed by both the representative of the contractor and the representative of the consumer. If the consumer's representative refuses to sign the logbook or sampling report, the representative of the contractor shall make a corresponding entry in the logbook or sampling report.

7. If the consumer fails to appoint an authorised representative for sampling, which shall be recorded in the refusal record (Appendix 12) with the signature of the contractor's representative, the contractor shall issue an invoice to the consumer for the excess discharge of pollutants with a multiplication factor K_k = 2 for the billing month in which the violation was committed.

In case of delay in admitting the authorised representative of the contractor to the consumer's territory (more than 30 minutes after his arrival) or creation of obstacles to sampling by the consumer's representatives, which is recorded in the

act (Appendix 12) signed by the contractor's representative, the contractor shall issue an invoice to the consumer for the excess discharge of pollutants with a multiplicity coefficient $K_{(k)} = 5$ for the billing month in which the violation was committed.

8. In the event of exceeding the maximum permissible concentrations of pollutants established by these Rules, the contractor shall, within five working days from the date of sampling, send a letter to the consumer notifying them of the detected exceedance of the maximum permissible concentrations of pollutants in the consumer's wastewater and the results of the chemical analysis.

Within a period not exceeding six months after determining the exceedance of permissible concentrations, the contractor shall send the consumer an invoice for the discharge of wastewater exceeding the permissible concentrations of pollutants.

9. If the consumer disagrees with the results of the contractor's laboratory data on the quality of wastewater according to the analysis of the control sample, the results of which conclude that the consumer's wastewater exceeds the maximum permissible concentrations of pollutants, the consumer has the right to apply to the contractor's laboratory for the analysis of arbitration samples, which are taken simultaneously with the control samples and stored properly by the contractor.

The opening of the arbitration sample and its analysis shall be carried out at the initiative of the consumer, in the presence of its representatives in the contractor's laboratory. The consumer has the right to involve representatives of the territorial body of the central executive authority that exercises state supervision (control) over compliance with environmental legislation (by agreement). The analysis of the arbitration sample at the initiative of the consumer may be carried out in another laboratory accredited and certified in this field in the presence of representatives of the contractor and the consumer. When analysing arbitration samples, another laboratory shall use the same methods of measuring the composition and properties of wastewater samples, measuring instruments and reagents as the contractor. The results of the chemical analysis of the arbitration sample shall be recorded in a corresponding act, the form of which is provided in Appendix 13 to these Rules, which is a sufficient legal basis for charging the consumer for the discharge of wastewater exceeding the maximum permissible concentration of pollutants.

VIII. Procedure for sampling wastewater for analysis

1. In order to control the quality of consumers' wastewater, the contractor shall take samples. Samples are usually taken manually, but automatic equipment may be used.

The samples characterise the chemical composition of the wastewater. Any exceedances of the maximum permissible concentrations of pollutants detected in this way shall be grounds for charging an additional fee in accordance with these Rules.

2. Depending on their purpose, samples are divided into control, arbitration and consumer samples, which are taken simultaneously.

3. Based on the results of the control sample analysis, the concentrations of pollutants (C_f) are determined and a conclusion is made regarding the absence or presence of pollutant concentrations exceeding the maximum permissible concentrations in the wastewater discharged into the centralised wastewater disposal system.

4. After sampling, the control sample is sent to the contractor's chemical laboratory for analysis. The consumer can obtain information about the chemical composition of the wastewater collected at the consumer's outlet by calling the contractor's chemical laboratory on the second day after the sample is collected. These records are recorded by the contractor in the logbook for informing consumers about the results of wastewater analysis (Appendix 14).

5. The sample for the consumer is taken with the consumer's consent, which is recorded in the logbook (Appendix 10). The consumer's consent or refusal to take such a sample is indicated by the words "yes" or "no" respectively and is certified by the consumer's signature. The analysis of this sample is carried out by the consumer. The consumer may not analyse the sample, agreeing with the results of the control sample analysis.

6. The arbitration sample is marked and sealed (sealing is carried out with paper tape using PVA glue) by a representative of the contractor and stored in the contractor's refrigerator for three days from the moment of sampling.

The marking paper tape shall contain the following information: date of sampling, name and code of the enterprise assigned by the contractor, control well number, position, surname, first name, patronymic and signature of the consumer's representative.

7. The analysis of the arbitration sample shall be carried out only for those ingredients for which the MCL of contaminants was exceeded in the control sample.

8. The results of the analyses of the control and arbitration samples shall be stored by the contractor indefinitely.

9. The minimum total volume of a single sample is 3.0 litres (1.0 litre in the container for the control sample, 1.0 litre in the container for the consumer sample and 1.0 litre in the container for the arbitration sample).

Samples shall be collected in containers specially prepared in accordance with the requirements of the measurement methods, DSTU ISO 5667-10:2005.

The selected samples are transported by vehicles equipped with refrigeration units and stored under the conditions specified in DSTU ISO 5667-10:2005, DSTU ISO 5667-3-2001.

10. The selection of control samples shall be recorded by the contractor in a logbook or sampling report (Appendices 10 and 11).

11. The results of the analysis of control and arbitration samples shall be entered into the Protocol of measurements of the composition and properties of wastewater samples in the form given in Appendix 15 to these Rules.

IX. Conditions for acceptance into the centralised wastewater disposal system of wastewater transported by sewage trucks (liquid domestic waste) from consumers and payment for the treatment of such wastewater

1. The acceptance into the centralised wastewater disposal system of liquid household waste generated in buildings in the absence of centralised wastewater disposal and accumulated in cesspools shall be carried out at the contractor's temporary discharge points. Discharge of such wastewater into the centralised water disposal system in places not agreed with the contractor is prohibited.

2. The transportation of liquid household waste to the place of acceptance (the contractor's discharge points) shall be carried out by a business entity that has the right to carry out this type of activity (carrier) using its own specialised motor vehicles on the basis of a contract concluded with the contractor for the acceptance and disposal of liquid household waste.

3. The actual volumes of wastewater transported by sewage transport from consumers and the cost of services provided by the contractor shall be specified in the contract for the reception and disposal of liquid household waste.

X. The amount of the fee charged for excessive wastewater discharges to centralised wastewater disposal systems

1. Provided that the quality and discharge regime of wastewater fully comply with these Rules and the terms of the concluded contract for the provision of drinking water supply and/or wastewater disposal services, consumers shall pay for wastewater disposal services at the rate established in accordance with the current legislation for the relevant category of consumers.

The amount of consumers' wastewater subject to payment shall be determined based on actual volumes in accordance with these Rules.

The volumes of wastewater generated as a result of precipitation, snowmelt and watering and washing during the cleaning of consumers' territories (hereinafter referred to as surface wastewater), and which enters the consumers' drainage networks in an unorganised manner or through rainwater collectors and wells on the drainage networks located on the consumers' territory, and subsequently enters the centralised drainage systems or directly into the contractor's drainage facilities, shall be paid for by consumers on the basis of contractual relations between the contractor and consumers, both in the case of a combined and a separate drainage system.

If the consumer's facility has a separate drainage system, where wastewater from the consumer's territory simultaneously enters the contractor's centralised drainage system and the storm drainage system of the city of Kyiv, the calculation for the volume of surface wastewater entering the centralised drainage system of the city of Kyiv is accepted at the level of 20% of the total water collection volume.

If, in the case of a separate drainage system on the consumer's territory, the contractor has established and recorded in an inspection report with the participation of the consumer's representative that there are soil collapses near

manhole covers, missing manhole covers, as well as a direct connection of storm water to the drainage network, the volume of wastewater is determined at 100% until the identified violations are eliminated.

The volume of wastewater generated as a result of precipitation (rain and melting snow and ice) and snowmelt and enters the centralised drainage system of the utility service provider in an unorganised manner is determined taking into account the area of atmospheric precipitation and snowmelt runoff from the territory occupied by the consumer, or part thereof, from which such wastewater actually enters in an unorganised manner.

The territory occupied by the consumer is indicated in the land plot plan with an indication of the area in hectares (extract from the State Cadastre database) or other supporting legal documents containing information on the area of the land plot.

The part of the area from which such wastewater actually enters the system in an unorganised manner is determined by conducting a comprehensive survey involving specialised institutions and providing the relevant approved documentation to the contractor.

The amount of wastewater entering the contractor's centralised drainage system during periods of rain and snowmelt through the manholes of the centralised drainage system and the receivers of the centralised drainage system's storm water system on the consumer's territory is calculated using the following formulas:

for a combined sewerage system – $Wg = 10hgYF$,

10 – conversion coefficient to a single measurement system F and hg;

hg – amount of precipitation for the reporting month, mm, determined by meteorological data;

Y – total runoff coefficient, which takes into account the amount of wastewater (layer or volume) that can enter the centralised drainage system over a certain period of time (month) from all atmospheric precipitation that fell during this period;

F – total area of the consumer's territory, ha.

for a separate drainage system – $Wg = 0.2(10hgYF)$.

The total runoff coefficient for storm water during the warm season for runoff areas with different surface types is determined on the basis of the data given in clause 7.3 of DSTU 3013-95 "HYDROSPHERE. Rules for controlling the drainage of rainwater and snowmelt from urban areas and industrial enterprises".

The total runoff coefficient for wastewater during the cold season, taking into account snow removal and water losses due to partial absorption by water-permeable surfaces during the thaw period, is 0.6 (in accordance with section 7.4 of DSTU 3013-95 "HYDROSPHERE. Rules for the control of rainwater and snowmelt runoff from urban areas and industrial enterprises").

The average annual volume of irrigation and washing water, Opm, entering

the street drainage network, in the absence of a metering device on the water pipeline supplying water for these purposes, and in the case of using water for irrigation and washing from an additional source of non-potable water supply, is determined by the formula:

Opm = 10mpYpmFpm,

where 10 – is the conversion factor to the unified measurement system Fpm and m;

M – specific water consumption for washing surfaces (taken as 1.35 l/m^{-2} per wash

P – is the average number of watering and washing operations per year (approximately 150), units;

Fpm – is the area of hard surfaces on which washing is carried out, ha;

Ypm – runoff coefficient for watering and washing water (taken to be 0.5).

If, in the case of a separate centralised drainage system on the consumer's territory, an inspection has established and recorded in an act with the participation of a representative of the utility service provider that it is impossible for wastewater from atmospheric precipitation to enter the centralised drainage system from the entire consumer's area or a separately located part thereof - the volume of wastewater from this area is equal to 0 (not determined).

2. Charges for additional volumes of surface wastewater generated by rain and snowmelt are calculated by the service provider and presented to consumers for payment on a monthly basis based on data from the Hydrometeorological Centre on the amount of precipitation in the previous month.

3. Consumers who discharge wastewater in the absence of a valid contract for centralised water supply and/or centralised wastewater disposal shall pay the contractor for the entire volume of wastewater discharged during the absence of such a contract at five times the established tariff for the centralised wastewater disposal service.

4. The amount of the fee for discharging wastewater into the contractor's centralised wastewater disposal system (P_c) shall be calculated by the contractor using the formula

$$P_c = T \times Q_d + 5T \times Q_{pd} + K_k \times T \times Q_{pz},$$

where: T – tariff set for the provision of centralised water drainage services to consumers belonging to the relevant category, UAH/m^3;

Q_d – the volume of wastewater discharged by the consumer within the limits specified in the contract, m^3;

Q_{pd} – volume of wastewater discharged by the consumer in excess of the volumes specified in the contract, m^3;

Q_{pz} – volume of wastewater discharged by the consumer with excessive pollution, m^3;

K_k – multiplicity coefficient, which takes into account the level of danger of discharged pollutants for wastewater treatment processes and the ecological state of the water body.

5. In the event of a sudden discharge of a pollutant, a multiplicity coefficient $K_k = 20$ shall be applied.

6. If the pH deviates from the established limits by 0.5 to 1.5 units inclusive, $K_k = 2$ shall be applied; from 1.5 to 2 units, $K_k = 5$ shall be applied; for 2 units and more, $K_k = 10$ shall be applied.

7. If the COD/BOC_5ratio exceeds ≤ 2.5, the multiplicity coefficient is determined by the formula

$$K_k = \frac{\text{ХСК}}{2{,}5 \times \text{БСК}_5} - 1,$$

where: COD – chemical oxygen demand;

BOC_5 – biological oxygen demand over 5 days.

8. If wastewater with a temperature above 40 ^{0}C or only mineral salts are discharged, $K_k = 2$ is applied.

9. For established violations of the requirements of paragraphs 2 (except for subparagraph 7) – 4 of Section IV of these Rules, a multiplier coefficient $K_k = 5$ shall be applied.

10. In case of violation of other general requirements (discharge of condensate, rainwater and drainage water in a separate drainage system, discharge of substances prohibited for discharge into the centralised drainage system, etc.), $K_k = 5$ shall apply.

11. If, during quality control of wastewater discharged by consumers, the contractor detects that the actual concentration of one type of pollution (C_f) exceeds the permissible concentration (PC) established by the Rules, the multiplicity coefficient (K_k) for calculating the fee for the discharge of excessive pollutants is determined by the formula

$$\mathbf{K_k = \frac{Cf}{ДК} - 1}$$

The multiplicity coefficient for exceeding the MC of a single substance may not exceed 5, except in the cases provided for in paragraphs 6 and 7 of this section.

12. If the contractor establishes that the consumer has discharged toxic or radioactive pollutants, the acceptance of which into the contractor's wastewater disposal system was not stipulated in the contract, the multiplicity coefficient $K_k = 5$.

13. If the contractor establishes the fact of simultaneous discharge into the centralised wastewater disposal system of several pollutants in concentrations exceeding the maximum permissible concentration, the multiplicity coefficient K_k is determined by the formula

$$K_k = \sum_{i=1}^{n} \frac{C_{fi} - \text{ДК}_i}{\text{ДК}_i}$$

where: C_{fi} – actual concentration of the i-th substance in the consumer's wastewater;

MC_i – permissible concentration of the i-th substance.

The total multiplicity coefficient, taking into account the exceedance of the permissible concentration of several substances and other violations, cannot exceed 10. If the calculated K_k exceeds 10, $K_k = 10$ is taken, except in cases provided for in paragraph 6 of this section.

14. The fee for the discharge of wastewater by the consumer in excess of the maximum permissible concentration of pollutants established by a single analysis shall be charged for the period from the previous sampling carried out by the contractor to the date of the recorded violation, but not more than ninety days. The increased fee shall be charged for the entire volume of wastewater discharged by the consumer from a specific facility during this period.

15. The fee for discharging wastewater into centralised drainage systems in violation of the requirements for the quality and mode of discharge shall be paid by the consumer to the contractor's current account at within ten days of receiving the relevant invoice.

16. For the additional amount of wastewater entering the contractor's centralised wastewater disposal systems during periods of rain and snowmelt through manholes and storm water receivers of the centralised wastewater disposal system on the consumer's territory, the latter shall pay in accordance with the requirements of the national Rules and these Rules.

APPENDIX 3

COUNCIL DIRECTIVE 91/271/EEC of 21 May 1991

«ON THE TREATMENT OF URBAN WASTE WATER»

THE COUNCIL OF THE EUROPEAN COMMUNITIES,

Having regard to the Treaty establishing the European Economic Community, and in particular Article 130s thereof,

Having regard to the proposal from the Commission,

Having regard to the opinion of the European Parliament, Having regard to the opinion of the Economic and Social Committee,

Whereas the Council Resolution of 28 June 1998 on the protection of the North Sea and other Community waters invited the Commission to submit proposals for measures to be taken at Community level for the treatment of urban waste water;

Whereas pollution resulting from inadequate treatment of waste water in one Member State often affects the quality of water in other Member States; whereas, in accordance with Article 130r, action at Community level is necessary;

Whereas, in order to avoid the harmful effects of inadequately treated urban waste water on the environment, there is a general need for secondary treatment of urban waste water;

Whereas there is a need to set stricter requirements for the treatment of waste water in environmentally sensitive areas; whereas in some less environmentally sensitive areas, primary treatment of waste water may be considered sufficient;

Whereas industrial wastewater entering wastewater sewerage systems, as well as wastewater discharges and sludge disposal from urban wastewater treatment plants, are subject to rules and regulations and/or special sanctions;

Since industrial effluents from certain industries that are biodegradable and do not enter wastewater treatment plants before being discharged into water bodies must meet special requirements;

Whereas the recycling of sludge produced during the treatment of waste water should be encouraged; whereas the discharge of sludge into surface water should be phased out;

Whereas it is necessary to monitor treatment plants, receiving waters and the use of sludge to ensure that the environment is protected from the adverse effects of sewage disposal;

Whereas it is important to provide the public with information on wastewater treatment and sludge in the form of periodic reports;

Whereas Member States should establish and submit to the Commission national programmes for the implementation of this Directive;

Whereas a committee shall be established to assist the Commission in the implementation of this Directive and its adaptation to technical progress,

HAS ADOPTED THIS DIRECTIVE:

Article 1

This Directive concerns the collection, treatment and discharge of urban waste water and the treatment and discharge of waste water from certain industries.

The purpose of the Directive is to protect the environment from the adverse effects of the above-mentioned discharges of waste water.

Article 2

For the purposes of this Directive, the following terms shall have the following meanings:

urban wastewater: domestic wastewater or a mixture of domestic and industrial wastewater and/or rainwater;

domestic wastewater: wastewater from residential areas and public utilities, the main source of which is human metabolism and domestic activities;

industrial wastewater: any wastewater discharged from properties used for trade or production that is not domestic waste or rainwater.

agglomeration: an area where the concentration of population and/or economic activity is sufficient to warrant the collection of wastewater and its conveyance to a wastewater treatment plant or final discharge point;

sewerage system: a system of pipes used to collect and transport wastewater;

1 p.e. (population equivalent): the load of organic substances subject to biological decomposition, with a five-day biochemical oxygen demand (BOD_5) equal to 60 g O_2 per day;

primary treatment: treatment of urban waste water by physical and/or chemical processes, including sedimentation of suspended solids, or other processes in which the BOD_5 in the initial waste water is reduced by at least 20 % before discharge, and the amount of suspended solids in the effluent is reduced by at least 50%.

secondary treatment: treatment of urban waste water by a process which, as a rule, includes biological treatment with secondary sedimentation, or another process which ensures compliance with the requirements set out in Table 1 of Annex I;

adequate treatment: treatment of urban waste water by any process and/or discharge system, after which the water body into which the water is discharged after treatment complies with the relevant water quality standards and conditions laid down in this and other Community Directives;

sludge: residual sludge, treated or untreated, from urban waste water treatment plants;

eutrophication: enrichment of water with nutrients, especially nitrogen and/or phosphorus compounds, leading to accelerated growth of algae and higher forms of plant life, resulting in undesirable disruption of the balance of organisms in the water and a reduction in its quality;

estuary: a transitional zone at the mouth of a river between fresh water and

coastal marine waters. Member States shall determine the outer (towards the sea) boundaries of estuaries for the purposes of this Directive as part of the implementation programme in accordance with the provisions of Article 17(1) and (2);

coastal waters: waters beyond the low-water line or beyond the outer limits of the estuary.

Article 3

Member States shall ensure that all agglomerations are provided with urban waste water treatment systems by 31 December 2000 for those agglomerations with a population- e equivalent (p.e.) of 15,000 or more, and by 31 December 2005 for agglomerations with a population equivalent of between 2,000 and 15,000.

With regard to discharges of urban waste water into water bodies considered to be 'sensitive areas' as defined in Article 5, Member States shall ensure that collection systems are installed by 31 December 1998 in agglomerations with a PE greater than 10,000.

If the establishment of a sewerage system is not justified because its implementation would not be beneficial to the environment or would involve excessive costs, individual or other appropriate systems that provide the same level of environmental protection shall be used.

The sewage systems described in Part 1 shall comply with the requirements of Part (A) of Annex I. These requirements may be amended in accordance with the procedure laid down in Article 18.

Article 4

Member States shall ensure that urban waste water entering sewage systems is treated by secondary or equivalent treatment within the following time limits:

by 31 December 2000 for all agglomerations with a population equivalent of more than 15,000;

until 31 December 2005 – for all agglomerations with a population equivalent of between 10,000 and 15,000,

until 31 December 2005 – for discharges into fresh water bodies and estuaries from agglomerations with a population equivalent of between 2,000 and 10,000.

Treatment of urban waste water discharged into water bodies located in high mountain regions (above 1,500 metres above sea level), where it is difficult to apply effective biological treatment due to low temperatures, may be carried out without strict compliance with the requirements of Part 1, provided that a detailed study concludes that these effluents have no negative impact on the environment.

Discharges from urban waste water treatment plants described in Parts 1 and 2 shall comply with the requirements set out in Part B of Annex I. These requirements may be amended in accordance with the procedure laid down in Article 18.

The substance load, expressed in PE, shall be calculated on the basis of the

maximum weekly average substance load in the effluent entering the treatment plant during the year, excluding exceptional situations, such as those resulting from heavy rainfall.

Article 5

For the purposes of Part 2, Member States shall, by 31 December 1993, identify sensitive areas in accordance with the criteria set out in Annex II.

Member States shall ensure that, by 31 December 1998, urban waste water entering sewerage systems from agglomerations with a population equivalent of more than 10,000 is subject to more stringent treatment than that described in Article 4 before being discharged into sensitive areas.

Waste water discharged from treatment plants referred to in paragraph 2 shall satisfy the relevant requirements set out in Part B of Annex I. These requirements may be amended in accordance with the procedure laid down in Article 18.

Alternatively, the requirements for individual plants set out in Parts 2 and 3 may not apply in sensitive areas if it can be demonstrated that the minimum percentage reduction in the total load of substances entering all treatment plants in the region is at least 75% for the total phosphorus load and at least 75% for the total nitrogen load.

Wastewater discharged from treatment plants located in the relevant catchment areas of vulnerable zones and polluting those regions shall be subject to the requirements of Parts 2, 3 and 4.

If the catchment area is located wholly or partly in the territory of another Member State, the provisions of Article 9 shall apply.

Member States shall ensure that the list of vulnerable zones is updated at least once every four years.

Member States shall ensure that, within seven years of an area being designated as vulnerable following a review in accordance with paragraph 6, the above requirements are met in that area.

A Member State shall not designate vulnerable zones for the purposes of this Directive if the entire territory of that Member State is covered by a system of waste water treatment meeting the requirements laid down in Parts 2, 3 and 4.

Article 6

For the purposes of Part 2, Member States may, until 31 December 1993, designate less sensitive areas in accordance with the criteria set out in Annex II.

Effluents from agglomerations with a population equivalent of between 10,000 and 150,000 into coastal waters and from agglomerations with a population equivalent of between 2,000 and 10,000 into estuaries, located in the regions described in Part 1, may be subject to less stringent treatment than that described in Article 4, provided that:

- such discharges are subject to at least primary treatment as defined in Article 2(7) of the, in accordance with the control procedures laid down in Part D of Annex I, comprehensive studies show that these discharges will not have an adverse effect on the environment.

Member States shall provide the Commission with all the information necessary for the above studies.

If the Commission considers that the conditions set out in paragraph 2 are not met, it shall submit a proposal to the Committee.

Member States shall update the list of less vulnerable areas at least once every four years.

7. Member States shall, within seven years after the zone has been removed from the list of less vulnerable zones, ensure that the relevant requirements of Parts 4 and 5 are implemented in that region.

Article 7

Member States shall, by 31 December 2005, ensure that urban waste water is adequately treated before discharge, in accordance with the requirements of Article 2, Part 9, in the following cases:

- for discharges from agglomerations with a population equivalent of less than 2,000 into freshwater bodies and estuaries,
- for discharges from agglomerations with a population equivalent of less than 10,000 into coastal marine waters.

Article 8

Member States may, in exceptional cases involving technical difficulties and for geographically defined population groups, submit a special request to the Commission for additional time to comply with the requirements of Article 4.

This request, which must be duly justified, shall describe the technical difficulties encountered and propose a programme of action with a timetable for achieving the objectives of this Directive. This timetable shall be included in the implementation programme referred to in Article 17.

Only reasons of a technical nature shall be considered valid, and the additional time referred to in paragraph 1 may not extend beyond 31 December 2005.

The Commission shall review the request and take the necessary measures in accordance with the procedure laid down in Article 18.

In exceptional circumstances, where it is demonstrated that more stringent treatment would not be beneficial to the environment, waste water from agglomerations with a population equivalent of more than 150,000 located in less sensitive regions may, before discharge, be subject to the treatment provided for in Article 6 for waste water from agglomerations with a population equivalent of between 10,000 and 150,000.

In such cases, Member States shall submit the relevant documentation to the Commission in advance. The Commission shall examine the situation and take action in accordance with the procedure laid down in Article 18.

Article 9

If water bodies in the territory under the jurisdiction of one Member State are adversely affected by the discharge of waste water in the territory of another

Member State, the Member State whose water bodies are adversely affected may notify the other Member State and the Commission.

The Member States concerned shall, if necessary with the assistance of the Commission, draw up a plan to identify the sources of discharges of waste water which have caused the situation and the measures to be taken in respect of those sources to protect the water bodies and ensure compliance with the requirements of this Directive.

Article 10

Member States shall ensure that urban waste water treatment plants established to meet the requirements of Articles 4, 5, 6 and 7 are designed, constructed, operated and maintained in such a way as to ensure proper functioning under normal local climatic conditions. The design of these plants shall take into account seasonal variations in the load of substances.

Article 11

Member States shall ensure that, by 31 December 1993, discharges of industrial waste water into sewerage systems and urban waste water treatment plants are carried out in accordance with the rules and/or specific sanctions laid down by the competent authorities or relevant institutions.

The rules and/or special authorisations shall comply with the requirements of Part C of Annex I. These requirements may be amended in accordance with the procedure laid down in Article 18.

The rules and special sanctions shall be reviewed regularly and amended as necessary.

Article 12

Treated waste water shall be reused, where appropriate, in such a way as to minimise its negative impact on the surrounding environment.

The competent authorities or relevant institutions shall ensure that the further use of wastewater after treatment is carried out in accordance with the applicable rules and/or specific authorisations.

Rules and/or authorisations for discharges of waste water, which are introduced to comply with the requirements of paragraph 2 concerning discharges into freshwater bodies and estuaries of agglomerations with a population equivalent of between 2,000 and 10,000 and all discharges of waste water from agglomerations with a population equivalent of more than 10,000, shall include conditions that satisfy the relevant requirements of Part B of Annex I. These requirements may be amended in accordance with the procedure laid down in Article 18.

The rules and/or penalties shall be reviewed regularly and amended if necessary.

Article 13

Member States shall ensure that, by 31 December 2000, biodegradable

industrial waste water from establishments belonging to the industrial sectors listed in Annex III, with a p.e. greater than 4,000, which are not sent to treatment plants before being discharged into water bodies, shall comply with the conditions laid down in the rules and/or specific sanctions in force, as established by the competent authorities or relevant institutions.

By 31 December 1993, the competent authorities or relevant institutions of each Member State shall establish requirements for the discharge of waste water, in accordance with the specific characteristics of the industrial sectors concerned.

The Commission shall, by 31 December 1994, carry out a comparison of the requirements of the Member States. It shall publish a report on the results of the comparison and, if necessary, make appropriate proposals.

Article 14

Sludge produced during the treatment of waste water shall, where appropriate, be reused in such a way as to minimise its negative impact on the environment.

The competent authorities or relevant institutions shall ensure that, by 31 December 1998, the reuse of sludge from treatment plants is carried out in accordance with general rules or is registered or licensed.

Member States shall ensure that, by 31 December 1998, the discharge of sludge into surface waters from ships, pipelines or by any other means is phased out.

Until the cessation of the forms of sludge disposal listed in paragraph 3, Member States shall ensure that the total amount of toxic, persistent or bioaccumulative materials in sludge to be disposed of in surface waters is licensed and progressively reduced.

Article 15

The competent authorities or relevant institutions shall monitor:

- discharges of effluent from urban waste water treatment plants in order to monitor compliance with the requirements of Part B of Annex I in accordance with the monitoring procedures laid down in Part D of Annex I
- the quantity and composition of sludge discharged into surface waters.

The competent authorities or relevant institutions shall monitor water bodies into which waste water is discharged from urban waste water treatment plants and directly from enterprises, as described in Article 13, in cases where the environment receiving the waste water can be expected to be significantly affected.

In cases where discharges of waste water are subject to the provisions of Article 6, as well as in cases of discharges of sludge into surface water bodies, Member States shall carry out monitoring and other necessary studies to confirm that the discharges do not have an adverse effect on the environment.

The information collected by the competent authorities or relevant institutions in accordance with paragraphs 1, 2 and 3 shall be kept in the Member

State concerned and shall be made available to the Commission within six months of the request.

Guidelines for the monitoring referred to in paragraphs 1, 2 and 3 may be drawn up in accordance with the procedure laid down in Article 18.

Article 16

Without prejudice to the implementation of the provisions of Council Directive 90/313/EEC of 7 June 1990 on the freedom of access to information on the environment, Member States shall ensure that the relevant authorities or bodies publish reports on the discharge of waste water and sludge in the regions under their jurisdiction every two years. These reports shall be forwarded to the Commission by the Member States immediately after their publication.

Article 17

Member States shall establish programmes for the implementation of this Directive by 31 December 1993. Member States shall provide the Commission with information on these programmes by 30 June 1994.

Member States shall, if necessary, provide the Commission with updated information as referred to in paragraph 2 every two years by 30 June.

The methods and forms to be used for reporting on national programmes shall be established in accordance with the procedure laid down in Article 18. Any amendments to these methods and forms shall be adopted in accordance with the same procedure.

The Commission shall review and evaluate the information received in accordance with the requirements of Parts 2 and 3 every two years and publish a report thereon.

Article 18

The Commission shall be assisted by a committee. Where reference is made to this Article, Articles 5 and 7 of Decision 1999/468/EC shall apply, having regard to the provisions of Article 8 thereof.

The period laid down in Article 5(6) of Decision 1999/468/EC shall be set at three months. The Committee shall adopt its rules of procedure.

Article 19

Member States shall bring into force the laws, regulations and administrative provisions necessary to comply with this Directive by 30 June 1993 at the latest and shall forthwith inform the Commission thereof.

When Member States adopt the provisions referred to in paragraph 1, they shall contain a reference to this Directive or be accompanied by such a reference on the occasion of their official publication. The methods of making such reference shall be laid down by Member States.

Article 20. This Directive is addressed to the Member States.

ANNEX I (to the EU Directive)

REQUIREMENTS FOR URBAN WASTE WATER

A. Sewage systems.

Sewage systems are subject to wastewater treatment requirements.

The design, construction and operation of sewage systems shall be carried out in accordance with using leading technologies, avoiding excessive costs, taking into account: the volume and characteristics of urban wastewater; prevention of wastewater leaks; limitation of pollution of water bodies into which wastewater is discharged as a result of overflowing storm sewers.

B. Discharge of wastewater from urban treatment plants into water bodies.

Wastewater treatment plants shall be designed or modified in such a way that it is possible to take samples of untreated and treated wastewater before discharge into water bodies.

Wastewater discharged from urban treatment plants and subject to treatment in accordance with Articles 4 and 5 shall meet the requirements set out in Table 1.

Wastewater discharged from urban treatment plants to vulnerable areas subject to eutrophication, as described in part (a) of section A of Annex II, shall also comply with the requirements set out in Table 2 of this Annex.

More stringent requirements than those specified in Table 1 and/or Table 2 shall apply in cases where effluent is required to meet the requirements of other relevant Directives.

The discharge points for urban waste water shall, as far as possible, be selected in such a way as to minimise the impact of the waste water on the receiving water body.

C. Industrial waste water.

Industrial wastewater entering sewerage systems and urban treatment plants shall be subject to preliminary treatment in order to:

- protect the health of personnel working with sewage systems and at treatment plants;
- prevent damage to sewage system equipment, treatment plants and associated equipment;
- ensure that urban wastewater treatment plants and sludge treatment facilities operate without disruption;
- ensure that wastewater discharges from treatment plants do not have a negative impact on the environment;
- ensure that sludge can be disposed of in a safe and environmentally acceptable manner.

Table 1. Requirements for wastewater discharged from municipal treatment plants are regulated by Articles 4 and 5 of the Directive

(concentration values or percentage reductions should be applied)

Parameters	Concentration	Min % reduction	Standard measurement method
Biochemical oxygen demand (BOD_5 at 20 °C) excluding nitrification	25 mg/l O_2	70 – 90 40 when used in accordance with Part 2 of Article 4	Homogenised, unfiltered, undecanted sample. Measurement of dissolved oxygen before and after five days of incubation at 20 °C± 1 °C, in complete darkness. Addition of nitrification inhibitor.
Chemical oxygen demand (COD)	125 mg/l O_2	75	Homogenised, unfiltered, undecanted sample potassium dichromate.
Total suspended solids	35 mg/l 35 (according to Part 2 of Article 4 (PE over 10,000) 60 (according to part 2 of Article 4 (PE 2000 – 10000)	90 90 (according to part 2 of Article 4 (PE over 10,000) 90 (according to part 2 of Article 4 (PE 2000 – 10000)	Filtering a representative sample through a 0.45 µm filter membrane. Drying at 105 °C and weighing. Centrifugation of a representative sample (for at least 5 minutes at an average acceleration of 2800 to 3200 g), drying at 105 °C and weighing.

(b) for the parameters in Table 1 expressed in concentrations, the results of samples that do not meet the requirements and that were taken under normal operating conditions shall not differ from the parametric values by more than 100%. For parametric values expressed in concentrations relative to the total amount of suspended solids, deviations of up to 150% are permitted;

(c) for the parameters specified in Table 2, the average annual value of the samples for each parameter shall comply with the specified parametric values.

The limit values for the quality of the water under investigation shall not be taken into account if they are the result of exceptional circumstances, such as excessive rainfall.

D. Standard methods for monitoring and evaluating results

Member States shall ensure that a monitoring method is used which meets at least the requirements set out below.

Methods alternative to those specified in parts 2, 3 and 4 may be used provided that the results obtained are equivalent.

Member States shall provide the Commission with all necessary information on the method they use. If the Commission considers that the conditions set out in Parts 2, 3 and 4 are not met, it shall submit a proposal to the Council.

In order to monitor the compliance of wastewater discharged into water bodies with the requirements set out in this Directive, it is necessary to take average proportional samples or samples regulated by time (once every 24 hours) at the same clearly defined discharge point and, if necessary, at the inlet to treatment plants.

To minimise the degradation of samples during the time between sampling and analysis, appropriate international laboratory methods shall be used.

The minimum annual number of samples is determined based on the size of the treatment plants, and these samples are collected at regular intervals throughout the year:

PE from 2000 to 9999:	12 samples during the first year. Four samples during subsequent years, if it can be determined that the water quality during the first year complies with the provisions of the Directive; if the results of one of the four samples are unsatisfactory, 12 samples should be taken in the following year.
PE from 10,000 to 49,999:	12 samples
PE over 50,000	24 samples

Treated wastewater is considered to comply with certain parameters if, for each individual parameter, the results of water samples show the following compliance with the parameter value:

(a) for the parameters specified in Table 1 and Part 7 of Article 2, the maximum number of samples that may not comply with the specified requirements, expressed in concentrations and/or percentages of reduction, is specified in Table 3;

Table 2. Requirements for discharges of wastewater from treatment plants into vulnerable areas where eutrophication is observed, as defined in section (a) of Part A of Annex II. One or both parameters may be used, depending on the situation on site (concentration values or percentage reductions should be applied).

Parameters	Concentration	Min % reduction	Standard measurement method
Total phosphorus	2 mg/l (PE 10,000-100,000) 1 mg/l (PE over 100,000)	80	Molecular absorption spectrophotometry
Total nitrogen	15 mg/l (PE 10,000-100,000) 10 mg/l (PE over 100,000)	70	Molecular absorption spectrophotometry

Table 3

Number of samples taken in any given year	Maximum permissible number of samples that may not meet the requirements
4	1
8	2
17 – 28	3
29 – 40	4
41 – 53	5
54 – 67	6
68 – 81	7
82 – 95	8
96 – 100	9
111 – 125	10
126 – 140	11
141 – 155	12
156 – 171	13
172 – 187	14
188 – 203	15
204 – 219	16
220 – 235	17
236 – 251	18
252 – 268	19
269 – 284	20
285 – 300	21
301 – 317	22
318 – 334	23
335 – 350	24
351 – 365	25

ANNEX II

CRITERIA FOR IDENTIFYING VULNERABLE AND LESS VULNERABLE AREAS

A. Vulnerable areas

A water body is considered a vulnerable area if it falls under one of the following definitions:

(a) natural freshwater lakes, other freshwater water bodies, estuaries and coastal marine waters that are eutrophic or are likely to become eutrophic in the near future unless preventive measures are taken.

When determining which nutrient content should be reduced through additional treatment, the following elements should be taken into account:

(i) lakes and rivers flowing into lakes/reservoirs/enclosed bays where there is insufficient water exchange, which may result in accumulation. In such regions, phosphorus content should be reduced unless it can be demonstrated that phosphorus removal will not affect eutrophication levels. Where discharges from large agglomerations are present, nitrogen removal may also be considered; (ii) estuaries, bays and other coastal marine waters where there is insufficient water

exchange or where large amounts of nutrients are discharged. Discharges from small agglomerations generally have a negligible impact on such areas, but phosphorus and/or nitrogen should be removed from discharges from large agglomerations unless it can be demonstrated that their removal will not affect the level of eutrophication;

(b) surface freshwater bodies intended for the abstraction of drinking water, in which the nitrate concentration may exceed the limit laid down in the relevant provisions of Council Directive 75/440/EEC of 16 June 1975 concerning the quality of water intended for human consumption in the Member States, unless precautionary measures are taken;

(c) regions where, in order to comply with the conditions of the Council Directives, more thorough treatment of waste water is required than that provided for in Article 4 of this Directive;

B. Less sensitive areas

A marine water body or area may be considered a less vulnerable area if the discharge of waste water does not have a negative impact on the surrounding environment due to the morphological, hydrological or hydraulic conditions specific to that region.

When identifying less vulnerable areas, Member States shall take into account the risk that may arise from the fact that waste water may be transferred to neighbouring areas where it may have a negative impact on the environment. Member States shall recognise the existence of vulnerable areas outside the territory under their jurisdiction.

When determining less vulnerable areas, attention should be paid to the following water bodies: open bays, estuaries and other coastal marine waters with adequate water exchange and which are not subject to eutrophication or oxygen depletion, or where it is considered unlikely that eutrophication or oxygen depletion will occur in these regions as a result of urban wastewater discharges.

ANNEX III

INDUSTRIAL SECTORS

Milk processing.
Production of fruit and vegetable products.
Production and bottling of non-alcoholic beverages.
Potato processing.
Meat processing industry.
Beer production.
Production of alcohol and alcoholic beverages.
Production of animal feed from plant products.
Production of gelatin and glue from offal, skin and bones.
Malt production.
Fish processing.

APPENDIX

DIRECTIVE (EU) 2024/1203 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 11 April 2024

on the protection of the environment through criminal law and replacing Directives 2008/99/EC and 2009/123/EC

THE EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION,

Having regard to the Treaty on the Functioning of the European Union, and in particular Article 83(2) thereof,

Having regard to the proposal from the European Commission,

After transmission of the draft legislative act to the national parliaments,

Having regard to the opinion of the European Economic and Social Committee ([1]),

Acting in accordance with the ordinary legislative procedure ([2]),

Whereas:

(1) Pursuant to Article 3(3) of the Treaty on European Union (TEU) and Article 191 of the Treaty on the Functioning of the European Union (TFEU), the Union is committed to ensuring a high level of protection and improvement of the quality of the environment. The environment, in a wide sense, should be protected, as follows from Article 3(3) TEU and Article 191 TFEU, covering all natural resources, including air, water, soil, ecosystems, including ecosystem services and functions, and wild fauna and flora, including habitats, as well as services provided by natural resources.

(2) Pursuant to Article 191(2) TFEU, Union policy on the environment is to aim at a high level of protection taking into account the diversity of situations in the various regions of the Union. That policy is to be based on the precautionary principle and on the principles that preventive action is to be taken, that environmental damage should as a priority be rectified at source and that the polluter should pay. Considering that environmental crime also affects fundamental rights, the fight against environmental crime at Union level is crucial to ensuring that those rights are protected.

(3) The rise in environmental criminal offences and their effects, which undermine the effectiveness of Union environmental law, is a matter of continuing concern in the Union. Such offences increasingly extend beyond the borders of the Member States in which they are committed. Such offences pose a threat to the environment and therefore necessitate an appropriate and effective response, which often requires effective cross-border cooperation.

(4) The existing rules on penalties under Directive 2008/99/EC of the European Parliament and of the Council ([3]) and under Union environmental sectoral law have not been sufficient to achieve compliance with Union law concerning protection of the environment. Such compliance should be strengthened by the availability of effective, proportionate and dissuasive criminal penalties that correspond to the gravity of the offences and can convey more social disapproval than the use of administrative penalties. Complementarity of criminal and administrative law is crucial to prevent and deter unlawful conduct that damages the environment.

(5) The list of environmental criminal offences in Directive 2008/99/EC should be revised and additional criminal offences based on the most serious breaches of Union environmental law should be added. Penalties should be strengthened in order to enhance their deterrent effect, and the effectiveness of the detection, investigation, prosecution and adjudication of environmental criminal offences should be improved.

(6) Member States should criminalise certain unlawful conduct, provide for greater precision with regard to the definition of relevant criminal offences and harmonise types and levels of penalties.

(7) Failure to comply with a legal duty to act can have the same negative effect on the environment and human health as active conduct. Therefore, the definition of criminal offences in this Directive should cover both acts and omissions, where applicable.

(8) Member States should provide for criminal penalties in their national law in respect of serious infringements of Union law concerning protection of the environment. In the framework of the common fisheries policy, Union law provides for a comprehensive set of rules for control and enforcement under Council Regulations (EC) No 1224/2009 ([4]) and (EC) No 1005/2008 ([5]) in the event of serious infringements, including those that cause damage to the marine environment. Under that set of rules, Member States have the choice of using administrative or criminal penalties, or both. In line with the communications of the Commission of 11 December 2019 on 'The European Green Deal' and 20 May 2020 on 'EU Biodiversity Strategy for 2030. Bringing nature back into our lives', certain intentional unlawful conduct covered by Regulation (EC) No 1224/2009 and Regulation (EC) No 1005/2008 should be established as a criminal offence.

(9) In order for conduct to constitute an environmental criminal offence under this Directive, it should be unlawful. In order for conduct to be unlawful, it should breach Union law which contributes to pursuit of one of the objectives of the Union's policy on the environment as set out in Article 191(1) TFEU, irrespective of the legal basis of such Union law, which could include, for example, Article 91, 114, 168 or 192 TFEU, or should breach laws, regulations or administrative provisions of a Member State, or decisions taken by a competent authority of a Member State, giving effect to such

Union law. This Directive should specify which unlawful conduct is capable of constituting a criminal offence and, where appropriate, set a quantitative or qualitative threshold necessary for such conduct to constitute a criminal offence. Such conduct should constitute a criminal offence when it is intentional and, in certain cases, also when carried out with at least serious negligence. In particular, unlawful conduct that causes the death of, or serious injury to, persons, substantial damage or a considerable risk of substantial damage to the environment or is considered otherwise to be particularly harmful to the environment should also constitute a criminal offence when carried out with at least serious negligence. Member States can adopt or maintain more stringent rules in the area of criminal law.

(10) Conduct should be unlawful even where it is carried out under an authorisation issued by a competent authority of a Member State if such authorisation was obtained fraudulently or by corruption, extortion or coercion. Furthermore, holding such an authorisation should not preclude the holder from being held criminally liable, where the authorisation is in manifest breach of relevant substantive legal requirements. 'In manifest breach of relevant substantive legal requirements' should be interpreted as referring to an obvious and substantial breach of relevant substantive legal requirements, and is not intended to include breaches of procedural requirements or minor elements of the authorisation. This does not shift the duty to ensure that authorisations are lawful from competent authorities to operators. Moreover, where an authorisation is required, the fact that the authorisation is lawful does not preclude criminal proceedings against the holder of the authorisation where that holder does not comply with all obligations of the authorisation or with other relevant legal obligations not covered by the authorisation.

(11) Moreover, it is necessary that operators take the necessary steps to comply with legislative, regulatory and administrative provisions concerning the protection of the environment applicable when they carry out the respective activity, including by complying with their obligations, as laid down in applicable Union and national law, in relation to procedures for the amendment or updating of existing authorisations. This should also cover obligations of the holder of the authorisation to update and renew such authorisation.

(12) With regard to offences and penalties defined in this Directive, the term 'legal persons' should be understood as not including States or public bodies exercising State authority or public international organisations. As this Directive establishes minimum rules, Member States can adopt more stringent rules, including rules on criminal liability for public bodies.

(13) Some criminal offences defined in this Directive include a qualitative threshold for the conduct to constitute a criminal offence, namely that such conduct causes the death of, or serious injury to, a person or substantial

damage to the quality of air, water or soil, or to an ecosystem, animals or plants. In order to protect the environment to the fullest extent possible, that qualitative threshold should be understood in a broad sense including, where relevant, substantial damage to fauna and flora, habitats, to services provided by natural resources and by ecosystems as well as to ecosystem functions. The term 'ecosystem' should be understood as a dynamic complex of plant, animal, fungi and microorganism communities and their non-living environment, interacting as a functional unit, and should include habitat types, habitats of species and species populations. An ecosystem should also include ecosystem services, through which an ecosystem contributes directly or indirectly to human wellbeing, and ecosystem functions, which refer to natural processes in an ecosystem. Smaller units such as a beehive, an anthill or a stump can be a part of an ecosystem but should not be considered to be an ecosystem in its own right for the purposes of this Directive.

(14) For the purposes of this Directive, the term 'injury' should be understood in a broad sense, that is as covering any form of physical harm to a person, including a change in body function or cell structure, a temporary, chronic or fatal disease, a malfunction of the body or other deterioration of physical health, but excluding mental health.

(15) The introduction of different forms of energy, such as heat, sources of thermal energy, noise, including underwater noise, and other sources of acoustic energy, vibrations, electromagnetic fields, electricity or light, into the environment can cause substantial damage to the quality of air, water or soil or substantial damage to an ecosystem, animals or plants, or the death of, or serious injury to, persons. Various instruments of Union environmental law regulate the introduction of energy into the environment, for example in the areas of protection of water, the marine environment, noise control, waste management and industrial emissions. In light of those instruments, the unlawful introduction of energy into the environment should constitute a criminal offence under this Directive if it causes or is likely to cause substantial damage to the environment or human health.

(16) Where criminal offences defined in this Directive relate to conduct such as making available or placing on the market, sale, offering for sale or trading, conduct carried out by means of information and communication technologies should be included.

(17) This Directive introduces the criminal offence of the placing on the market, in breach of a prohibition or another requirement aimed at protecting the environment, of a product the use of which on a larger scale results in the discharge, emission or introduction of a quantity of materials or substances, energy or ionising radiation into air, soil or water, and causes or is likely to cause substantial damage to the environment or human health. In that context, a prohibition or another requirement aimed at protecting the environment should be one that is laid down in the area of Union law which has among its

stated objectives, or has as an aim, the protection of the environment, including preserving, protecting and improving the quality of the environment, protecting human health, prudent and rational utilisation of natural resources or combatting climate change, or promoting measures at international level to deal with regional or worldwide environmental problems. Conversely, where such a prohibition or requirement is laid down in other areas of Union law which have other objectives, for example protection of workers' health and safety, the conduct should not be covered under that criminal offence. For the purpose of this Directive, 'use on a larger scale' refers to the combined effect of the use of the product by several users, regardless of their number, provided that the conduct causes or is likely to cause damage to the environment or human health.

(18) Unlawful collection, transport and treatment of waste and the lack of supervision of such operations and of the after-care of disposal sites, including action taken as a dealer or a broker, can cause devastating effects on the environment and human health. Such effects can be caused by unlawful conduct which concerns harmful waste from pharmaceutical products, narcotic drugs, including components to produce narcotic drugs, chemicals, waste containing acids or bases or waste containing toxins, heavy metals, oil, grease, electrical and electronic waste, end-of-life vehicles or plastic waste. Member States should, therefore, ensure that unlawful waste management constitutes a criminal offence where such conduct concerns hazardous waste in a non-negligible quantity, or it concerns other waste and such other waste causes or is likely to cause substantial damage to the environment or human health.

(19) For the purpose of the criminal offence introduced by this Directive in relation to recycling of ships falling within the scope of Regulation (EU) No 1257/2013 of the European Parliament and of the Council ([6]) it is to be noted that, currently under Union law, the obligations set out in that Regulation only apply to ship owners, as defined in that Regulation.

(20) With regard to the assessment of whether the quantity of a relevant product or relevant commodity associated with deforestation or forest degradation as referred to in Regulation (EU) 2023/1115 of the European Parliament and of the Council ([7]), is negligible, Member States could take into account, for example, the quantity of the relevant commodity or product expressed in net mass, or, where applicable, in volume or as a number of items, or whether the scale of the activity in question is negligible in terms of quantity. For such assessment, Member States could also take into account, where relevant, other elements listed in this Directive for certain criminal offences, including the conservation status of the species concerned or the cost of restoration of the environment.

(21) Criminal offences relating to intentional conduct listed in this Directive can lead to catastrophic results, such as widespread pollution, industrial accidents

with severe effects on the environment or large-scale forest fires. Where such offences cause the destruction of, or widespread and substantial damage which is either irreversible or long-lasting to, an ecosystem of considerable size or environmental value or a habitat within a protected site, or cause widespread and substantial damage which is either irreversible or long-lasting to the quality of air, soil, or water, such offences, leading to such catastrophic results, should constitute qualified criminal offences and, consequently, be punished with more severe penalties than those applicable in the event of other criminal offences defined in this Directive. Those qualified criminal offences can encompass conduct comparable to 'ecocide', which is already covered by the law of certain Member States and which is being discussed in international fora.

(22) Where, under this Directive, conduct constitutes a criminal offence only if it concerns a non-negligible quantity, corresponding to the exceeding of a regulatory threshold, value or other mandatory parameter, in assessing whether that threshold, value or other parameter has been exceeded, the hazardousness and toxicity, inter alia, of the material or substance should be taken into account because the more hazardous or toxic the material or substance is, the sooner that threshold, value or other parameter is reached and, in the case of particularly hazardous and toxic substances or materials, even a very small quantity can cause substantial damage to the environment or human health.

(23) The acceleration of climate change, biodiversity loss and environmental degradation, paired with tangible examples of their devastating effects, have led to the recognition of the green transition as the defining objective of our time and a matter of intergenerational equity. Where this Directive, in order to define criminal offences, uses terms defined in Union environmental law to describe unlawful conduct, such terms should be understood within the meaning of the corresponding definitions laid down in the relevant Union legal acts covered by this Directive. This Directive should also cover any Union acts that amend provisions or requirements relevant to describing unlawful conduct which falls within the scope of criminal offences defined in this Directive. When drafting such amending Union acts, it would be appropriate to include a reference to this Directive. However, where new types of unlawful conduct, not yet covered by the scope of the offences defined in this Directive, are introduced in Union environmental law, this Directive should be amended to include such new types of unlawful conduct within its scope.

(24) Without prejudice to that dynamic nature of this Directive, the Commission should regularly, and where necessary, consider if there is a need to amend the description in this Directive of conduct capable of constituting a criminal offence under this Directive. The Commission should also consider if there is a need to define other criminal offences when new types of unlawful conduct not yet covered by the scope of this Directive are introduced in Union

environmental law.

(25)This Directive should provide a non-exhaustive list of elements which should be taken into account, where relevant, by the competent authorities, in assessing whether the qualitative and quantitative thresholds used to define environmental criminal offences have been reached. Providing such a list should facilitate the coherent application of this Directive and a more effective fight against environmental crime as well as provide for legal certainty. However, such assessment elements or their application should not make the detection, investigation, prosecution or adjudication of criminal offences excessively difficult.

(26)Where this Directive provides that an unlawful conduct only constitutes a criminal offence where it is carried out intentionally and causes the death of a person, the notion of 'intention' should be interpreted in accordance with national law, taking into account relevant case law of the Court of Justice of the European Union (the 'Court of Justice').Therefore, for the purposes of this Directive, 'intention' could be understood as the intention to cause the death of a person, or it could also cover a situation in which the offender, despite not wanting to cause the death of a person, nevertheless accepts the likelihood of causing it, and acts, or refrains from acting, voluntarily and in violation of a particular obligation, thereby causing the death of a person. The same understanding as regards the notion of 'intention' should apply where unlawful conduct described in this Directive, which is intentional, causes serious injury to any person, or the destruction of, or widespread and substantial damage which is either irreversible or long-lasting to, an ecosystem of considerable size or environmental value or a habitat within a protected site, or causes widespread and substantial damage which is either irreversible or long-lasting to the quality of air, soil, or water.

(27)With regard to the criminal offences defined in this Directive, the notion of 'serious negligence' should be interpreted in accordance with national law, taking into account relevant case law of the Court of Justice. This Directive does not require the introduction in national law of the notion of 'serious negligence' for each constituent element of the criminal offence, such as possession, sale or offering for sale, placing on the market and similar elements. In such cases, it is possible for Member States to decide that the notion of 'serious negligence' is relevant for elements of the criminal offence such as the protection status, 'negligible quantity', or the 'likelihood' of the conduct to cause substantial damage.

(28)In criminal proceedings and trials, due account should be taken of the involvement of organised criminal groups operating in ways that negatively impact the environment. Criminal proceedings for environmental offences should address corruption, money laundering, cyber-crime and document fraud and, in relation to business activities, the intention of the offender to maximise profits or save expenses. Such forms of crime are often

interconnected with serious forms of environmental crime and should therefore not be dealt with in isolation. They are also prone, in particular, to causing substantial damage to the environment and human health, including devastating effects on nature and local communities. In addition, it is of particular concern that some environmental criminal offences are committed with the tolerance or active support of the competent administrations or officials performing their public duty. In certain cases, this can even take the form of corruption. Examples of such behaviour are turning a blind eye to, or remaining silent on, the infringement of environmental law following inspections, deliberately omitting inspections or controls such as with regard to whether the conditions of a permit are being respected by the permit-holder, supporting resolutions or voting in favour of granting illegal licences, or issuing falsified or untrue favourable reports.

(29) Inciting, and aiding and abetting intentional commission of a criminal offence should also be punishable. An attempt to commit a criminal offence that causes or is likely to cause the death of, or serious injury to, any person or causes or is likely to cause substantial damage to the environment or is otherwise considered particularly harmful should also constitute a criminal offence when committed intentionally. The notion of 'attempt' is interpreted in accordance with national law. With regard to the criminal offence defined in this Directive in relation to the execution of a project without a development consent, since the execution of a project is to be understood as including the start of the implementation of such a project, for example works to prepare the ground for construction or other intervention with effects on the environment, this Directive does not list that offence among criminal offences for which an attempt should be punishable as a criminal offence.

(30) Penalties for the criminal offences defined in this Directive should be effective, dissuasive and proportionate. To that end, minimum levels for the maximum term of imprisonment should be set for natural persons. The maximum terms of imprisonment provided for in this Directive for the criminal offences committed by natural persons should apply at least to the most serious forms of such offences. The criminal law of all Member States includes provisions on homicide, either committed intentionally or with serious negligence. Member States should be able to have recourse to those general provisions, including provisions on aggravating circumstances, when transposing the provisions in this Directive that relate to criminal offences that cause the death of a person, whether committed intentionally or with serious negligence.

(31) Accessory penalties or measures are often seen as being more effective than financial penalties, especially for legal persons. Accessory penalties or measures should be therefore available in the relevant proceedings. Those penalties or measures could include the obligation to restore the environment, the exclusion from access to public funding, including tender procedures, grants and concessions, and the withdrawal of permits and authorisations.

This is without prejudice to the discretion of judges or courts in criminal proceedings to impose appropriate penalties in individual cases.

(32) Accessory penalties or measures could, without prejudice to the requirements of Directive 2004/35/EC of the European Parliament and of the Council ([8]), include a requirement to restore the environment where the damage is reversible and a requirement to provide compensation where the damage is irreversible or the offender lacks the capacity to carry out such restoration.

(33) To the extent that conduct constituting an environmental criminal offence as defined in this Directive is attributable to legal persons, such legal persons should be held liable for such an offence. In order to achieve the objectives of this Directive, Member States whose law provides for the criminal liability of legal persons should ensure that their law provides for effective, dissuasive and proportionate types and levels of criminal penalties as laid down in this Directive. In order to achieve the objectives of this Directive, Member States whose law does not provide for the criminal liability of legal persons should ensure that their law provides for effective, dissuasive and proportionate types and levels of non-criminal penalties as laid down in this Directive. The maximum levels of fines provided for in this Directive for the criminal offences defined in it should apply at least to the most serious forms of such offences. The gravity of the conduct, as well as the individual, financial and other circumstances of the legal persons concerned, should be taken into account to ensure that the penalty imposed is effective, dissuasive and proportionate. Member States should be able to set the maximum levels of fines either as a percentage of the total worldwide turnover of the legal person concerned, or in fixed amounts. Member States should decide which of those two options they will use, when transposing this Directive.

(34) Where Member States, in the determination of fines to be imposed on legal persons, opt to implement the criterion of the total worldwide turnover of a legal person, they should decide whether to calculate that turnover based on the business year preceding that in which the criminal offence was committed, or on the business year preceding that of the decision to impose the fine. They should also consider providing for rules for cases where it is not possible to determine the amount of a fine on the basis of the total worldwide turnover of the legal person in the business year preceding that in which the criminal offence was committed, or in the business year preceding that of the decision to impose the fine. In such cases, Member States should be able to take into account other criteria, such as total worldwide turnover in a different business year. Where those rules include the setting of fixed amounts of fines, it should not be necessary for the maximum levels of those amounts to reach the levels established in this Directive as the minimum requirement for the maximum level of fines set in fixed amounts.

(35) Where Member States opt for a maximum level of fines set in fixed amounts, such levels should be laid down in national law. The highest levels of such

fines should apply to the most serious forms of criminal offences defined in this Directive committed by legal persons of financial strength. Member States should be able to determine the method of calculation of those highest levels of fines, including specific conditions therefor. Member States are invited to regularly review the levels of fines set in fixed amounts having regard to rates of inflation and other fluctuations in monetary value, in accordance with procedures laid down in their national law. Member States that do not have the euro as their currency should provide for maximum levels of fines in their currency that correspond to the levels determined in this Directive in euro on the date of its entry into force. Those Member States are invited to regularly review the levels of fines also with regard to the development of the exchange rate.

(36) The establishment of the maximum level of fines is without prejudice to the discretion of judges or courts in criminal proceedings to impose appropriate penalties in individual cases. As this Directive does not establish any minimum levels of fines, the judges or courts should, in any case, impose appropriate penalties taking into account the individual, financial and other circumstances of the legal person concerned and the gravity of the conduct.

(37) Member States should ensure that the criminal or non-criminal penalties or measures applicable to legal persons held liable for qualified criminal offences as defined in this Directive are more severe than those applicable in the event of other criminal offences defined in this Directive. To that end, Member States should, in accordance with their national law, provide for a higher level of criminal and non-criminal fines than the maximum level of fines established in this Directive or otherwise provide for more severe penalties or measures, including criminal or non-criminal penalties or measures, or a combination thereof.

(38) The fact that legal persons are held liable under this Directive should not preclude criminal proceedings being taken against natural persons who commit, incite or are accessories to the criminal offences defined in this Directive. Where the conditions for criminal liability are met, such natural persons should be understood to include corporate board members.

(39) It is necessary that Member States consider introducing penalties or measures that are an alternative to imprisonment in order to contribute to the restoration of the environment.

(40) Penalty levels imposed should be further approximated and the effectiveness of such levels should be fostered through introducing common aggravating circumstances that reflect the gravity of the criminal offence committed. The notion of ‘aggravating circumstances’ should be understood either as facts enabling the judge to pronounce more severe sentences for the same criminal offence than the sentence normally imposed without such facts, or as the possibility to treat several criminal offences cumulatively in order to increase the level of penalty. Therefore, Member States are not obliged to provide for

specific aggravating circumstances where national law already provides for separate criminal offences that can lead to more severe penalties.

(41) Member States should ensure that at least one of the aggravating and mitigating circumstances provided for in this Directive is provided for as a possible aggravating or mitigating circumstance in accordance with applicable rules in their legal system. In any case, it should remain within the discretion of the judge or the court to determine whether to increase or to decrease the sentence, taking into account the specific circumstances in each individual case.

(42) This Directive should apply without prejudice to the general rules and principles of national criminal law on the sentencing or the execution of sentences in accordance with the specific circumstances in each individual case. It should be possible for Member Stats to determine the most appropriate types of accessory penalties or measures. In particular, where national law provides for the possibility to impose an obligation to restore the environment within a given period, provided that the damage is reversible, this Directive does not require that a judge or a court also be responsible for monitoring the execution of such obligation. Similarly, if the withdrawal of permits and authorisations to pursue activities that resulted in the relevant criminal offence can be imposed as a penalty under national law, Member States should ensure that judges or courts are able to either impose such a penalty themselves or that another competent authority is informed and can act in accordance with national procedural rules.

(43) This Directive should not affect civil liability under national law or the obligation to compensate, in accordance with Union or national law, for harm or damage caused as a result of a given criminal offence defined in this Directive.

(44) The publication of the personal data of convicted persons contained in judicial decisions should only be possible in duly justified exceptional cases following a case-by-case assessment, weighing the public interest against the rights to respect for private life and protection of the personal data of the convicted person provided for in Articles 7 and 8 of the Charter of Fundamental Rights of the European Union (the 'Charter'), respectively. The publication of those personal data should therefore only be possible in cases of serious criminal offences and where strong dissuasive effects are needed. The case-by-case assessment could take into account elements such as the gravity of the damage caused to the environment, the harm suffered by natural persons, or both, whether the criminal offence has been committed repeatedly in the same environmental sector, and whether the criminal offence was committed by or for the benefit of a large company active in several Member States or by an important market player in a specific environmental sector. Any processing of personal data in the context of this Directive should comply with the applicable Union and national data protection legislation, in particular

Regulation (EU) 2016/679 of the European Parliament and of the Council ([9]) and Directive (EU) 2016/680 of the European Parliament and of the Council ([10]). That data protection legislation includes an obligation for Member States to provide for appropriate safeguards for the rights and freedoms of data subjects when publishing all or part of the judicial decision that relates to the criminal offence committed and the penalties or measures imposed. Additionally, the publication of the decision imposing the penalties or measures upon a legal person should be applied without prejudice to the national rules governing the anonymisation of judicial decisions or the duration of publication.

(45) The obligation provided for in this Directive to provide for criminal penalties should not exempt Member States from the obligation to provide for administrative penalties and other measures in national law for breaches of Union environmental law.

(46) Member States should define the scope of administrative and criminal law enforcement clearly with regard to environmental offences, in accordance with their national law. In the application of national law transposing this Directive, Member States should ensure that the imposition of criminal penalties and of administrative penalties respects the principles of the Charter, including the prohibition of proceedings that do not respect the principle of *ne bis in idem*.

(47) Furthermore, judicial and administrative authorities in the Member States should have at their disposal a range of criminal and non-criminal penalties and other measures, including preventive measures, to address different types of criminal conduct in a tailored, timely, proportionate and effective manner.

(48) Where criminal offences are of a continuing nature, they should be brought to an end as soon as possible. Member States are encouraged to enable the competent authorities to order the immediate cessation of the unlawful conduct or to prevent such conduct.

(49) Where offenders have made financial gains, such gains should be confiscated. Member States should take the necessary measures to allow frozen and confiscated proceeds and instrumentalities to be appropriately managed, in line with their nature. Member States should consider taking measures allowing confiscated property to be used, where possible, to finance restoration of the environment or remediation of any damage caused, or to provide compensation for the environmental damage, in accordance with national law.

(50) Member States should lay down rules concerning limitation periods necessary to combat environmental crime effectively, without prejudice to national rules that do not set limitation periods for investigation, prosecution and enforcement. As a general rule, a limitation period runs from the point in time the criminal offence was committed. However, as this Directive establishes minimum rules, Member States can provide for the limitation period to start

later, namely from the point in time the criminal offence was detected, provided that such point in time of detection is clearly determined in accordance with national law. Member States are permitted under this Directive to establish limitation periods shorter than those laid down in this Directive, provided that in their legal systems it is possible to interrupt or suspend such shorter limitation periods in the event of acts which can be specified in accordance with national law.

(51) Given, in particular, the mobility of offenders, together with the cross-border nature of criminal offences defined in this Directive and the possibility of cross-border investigations being carried out, Member States should establish jurisdiction in order to combat such offences effectively. Member States should cooperate with Eurojust, in particular on the basis of Regulation (EU) 2018/1727 of the European Parliament and of the Council ([11]), in cases where conflicts of jurisdiction could arise. A given Member State should establish jurisdiction over criminal offences committed on board a ship or an aircraft registered in that Member State, or flying its flag, taking into account related standards under relevant international conventions. Member States should not be obliged under this Directive to establish for the first time such jurisdiction over criminal offences that, due to their nature, cannot be committed on board a ship or an aircraft.

(52) Member States should establish jurisdiction over criminal offences defined in this Directive where the damage which is one of the constituent elements of the criminal offence occurred on their territory. In accordance with national law, and in line with the territoriality principle, a Member State could establish jurisdiction over criminal offences committed in whole or in part on its territory.

(53) To ensure successful enforcement of environmental criminal law, Member States should make available to competent authorities effective investigative tools for environmental criminal offences such as those available under their national law for combatting organised crime or other serious criminal offences, if and to the extent that the use of those tools is appropriate and proportionate to the nature and gravity of the criminal offences as provided for in national law. Such tools could include the interception of communications, covert surveillance, including electronic surveillance, controlled deliveries, the monitoring of bank accounts and other financial investigation tools. Those tools should be used in line with the principle of proportionality and in full respect of the Charter. It is imperative that the right to the protection of personal data be respected.

(54) Environmental criminal offences harm nature and society. Persons reporting breaches of Union environmental law perform a service of public interest and play a key role in exposing and preventing such breaches, and thus in safeguarding the environment and the welfare of society. Individuals in contact with an organisation in the context of their work-related activities are

often the first to know about threats or harm to the public interest and the environment. Persons who report irregularities are known as 'whistleblowers'. Potential whistleblowers are often discouraged from reporting their concerns or suspicions for fear of retaliation. Such reporting persons benefit from balanced and effective protection under Directive (EU) 2019/1937 of the European Parliament and of the Council ([12]), which includes Directives 2008/99/EC and 2009/123/EC ([13]) of the European Parliament and of the Council within its scope. Following the replacement of Directives 2008/99/EC and 2009/123/EC by this Directive, persons who report breaches of Union environmental law should, by virtue of this Directive, continue to benefit from that protection from the Member States bound by it.

(55) Persons other than those who report breaches of Union law under Directive (EU) 2019/1937 could also possess valuable information concerning potential environmental criminal offences. They could be members of the community affected or members of society as a whole taking an active part in protecting the environment. Such persons who report environmental criminal offences as well as persons who cooperate with regard to the enforcement of such offences should be provided with the necessary support and assistance in the context of criminal proceedings, so that they are not disadvantaged as a result of their cooperation but supported and assisted. The necessary support and assistance measures should be available to such persons in accordance with their procedural rights in national law and should include, at least, all support and assistance measures available to persons having corresponding procedural rights in criminal proceedings concerning other criminal offences. Those persons should, in accordance with their procedural rights in national law, also be protected from being persecuted for reporting environmental criminal offences or for their cooperation in the criminal proceedings. The content of the necessary support and assistance measures is not established by this Directive and should be determined by Member States. Member States are not required to make available the support and assistance measures to persons who are suspected or accused in the context of the criminal proceedings concerned.

(56) Member States should assess the need to enable persons to report environmental criminal offences anonymously, where such possibility does not already exist.

(57) Since the environment cannot represent itself as a victim in criminal proceedings, for the purpose of effective enforcement, members of the public concerned should have the possibility of acting on behalf of the environment as a public good, in accordance with national law and subject to the relevant procedural rules.

(58) This Directive does not require Member States to introduce new procedural rights for the members of the public concerned. However, when such procedural rights for members of the public concerned exist in a Member

State in equivalent situations concerning criminal offences other than those provided for pursuant to this Directive, such as the right to participate in proceedings as a civil party, such procedural rights should also be granted to the members of the public concerned in proceedings concerning the environmental criminal offences defined in this Directive. The rights of the members of the public concerned are without prejudice to the rights of victims as set out in Directive 2012/29/EU of the European Parliament and of the Council ([14]). The notion of 'members of the public concerned' and of 'victims' should remain distinct and Member States should not be required to apply victims' rights to members of the public concerned. This Directive does not require Member States to grant to members of the public concerned the procedural rights in criminal proceedings that they grant to categories of persons other than members of the public concerned.

(59) Member States should take appropriate measures, such as information and awareness-raising campaigns targeting relevant stakeholders both from the public and private sector, as well as research and education programmes, that aim to reduce overall environmental criminal offences and the risk of environmental crime. Where appropriate, Member States should act in cooperation with such stakeholders. In that context, measures that aim to improve prevention of environmental criminal offences could include promoting compliance and due diligence schemes, encouraging operators to have compliance officers to help ensuring compliance with Union environmental law, and promoting transparency in order to strengthen compliance with environmental criminal law. In addition, accessory penalties imposed on legal persons under this Directive could include an obligation on companies to install due diligence schemes for enhancing compliance with environmental standards, which also contributes to prevention of further environmental criminal offences. Moreover, Member States could consider establishing a fund to support prevention measures in respect of environmental criminal offences and their devastating consequences.

(60) Lack of resources and enforcement powers for national authorities which detect, investigate, prosecute or adjudicate environmental criminal offences creates obstacles for the effective prevention and sentencing of those offences. In particular, the shortage of resources is capable of preventing authorities from taking any action or limiting their enforcement actions, allowing offenders to escape liability or to receive a sentence that does not correspond to the gravity of the criminal offence. Therefore, minimum criteria concerning resources and enforcement powers should be established.

(61) The effective functioning of the enforcement chain depends on a range of specialist skills. As the complexity of the challenges posed by environmental criminal offences and the technical nature of such offences require a multidisciplinary approach, a high level of legal knowledge and technical expertise, financial support, as well as a high level of training and specialisation within all relevant competent authorities, are necessary.

Member States should provide training appropriate to the functions of those in charge of detecting, investigating, prosecuting or adjudicating environmental crime. Where appropriate, Member States should, taking into account their constitutional traditions and structure of their legal systems, as well as other circumstances, including the size of the Member State concerned, assess the need to increase the level of specialisation of such authorities in the area of environmental criminal offences, in accordance with national law. Where the Member State concerned is small and has only a limited number of competent authorities, the assessment might conclude that, in view of that limited number, specialisation is not possible or advisable. In particular, to maximise the professionalism and effectiveness of the enforcement chain, Member States should also consider assigning specialised investigation units, prosecutors and judges to deal with environmental criminal cases. General criminal courts could provide for specialised chambers of judges. Technical expertise should be made available to all relevant enforcement authorities.

(62) To ensure an effective, integrated and coherent enforcement system that includes administrative, civil and criminal law measures, Member States should organise internal cooperation and communication between all their competent authorities involved in administrative and criminal enforcement, including all authorities exercising preventive, penal and remedial functions.

(63) In accordance with applicable rules, Member States should also cooperate between them through Union agencies, in particular Eurojust and Europol, as well as with Union bodies, including the European Public Prosecutor's Office and the European Anti-Fraud Office, in their respective areas of competence. Without prejudice to the rules on cross-border cooperation and mutual legal assistance in criminal matters, such cooperation should be provided to ensure effective action against the criminal offences defined in this Directive, and include technical and operational assistance provided, where appropriate, by Eurojust to the national competent authorities as needed by those authorities to coordinate their investigations. The Commission could, where appropriate, provide assistance. Such assistance should not entail the participation of the Commission in the investigation or prosecution procedures of individual criminal cases conducted by the national competent authorities and should not be understood as including financial support or any other budgetary commitment by the Commission.

(64) Member States should ensure that information on persons convicted for the criminal offences defined in this Directive is exchanged between national competent authorities in accordance with Council Framework Decision 2009/315/JHA ([15]).

(65) To ensure a coherent approach to combatting environmental crime, Member States should adopt, publish, implement and periodically review a national strategy on combatting environmental criminal offences, establishing

objectives, priorities and the corresponding measures and resources needed. That national strategy should address, in particular, the objectives and priorities of national policy in the area of environmental crime, the methods of coordination and cooperation between the competent authorities, the procedures and mechanisms for regular monitoring and evaluation of the results achieved, and the assistance of European networks working on matters directly relevant to combatting environmental criminal offences and related infringements. It should be possible for Member States to determine the appropriate form for that strategy which could take into account their constitutional traditions in terms of separation of powers and competences, and be either sectoral or a part of a broader strategic document. Irrespective of whether Member States provide for the adoption of one or more strategies, their overall content should encompass the territory of the entire Member State.

(66) To effectively tackle the environmental criminal offences defined in this Directive, it is necessary that competent authorities in the Member States collect accurate, consistent and comparable statistical data on those offences. Member States should therefore ensure that an adequate system is in place for the recording, production and transmission of existing statistical data on the offences defined in this Directive. Those statistical data should be used by Member States to serve the strategic and operational planning of enforcement activities, to analyse the scale of and trends in environmental criminal offences, as well as for providing information to citizens. Member States should transmit to the Commission relevant statistical data on environmental crime proceedings, extracted from data that already exist at a centralised or decentralised level within the whole Member State. The Commission should regularly assess and publish in a report the results of its assessment based on the statistical data transmitted by the Member States.

(67) The statistical data transmitted under this Directive on environmental criminal offences should be comparable between the Member States and extracted on the basis of common minimum standards. In order to ensure uniform conditions for the implementation of this Directive, implementing powers should be conferred on the Commission to establish the standard format for the transmission of statistical data. Those powers should be exercised in accordance with Regulation (EU) No 182/2011 of the European Parliament and of the Council ([16]).

(68) The standard format for the transmission to the Commission of statistical data on types and levels of penalties, including information on the related offence categories, in accordance with this Directive should be established in accordance with the committee procedure provided for in this Directive.

(69) In accordance with Articles 1 and 2 and Article 4a(1) of Protocol No 21 on the position of the United Kingdom and Ireland in respect of the area of freedom, security and justice, annexed to the TEU and to the TFEU, and

without prejudice to Article 4 of that Protocol, Ireland is not taking part in the adoption of this Directive and is not bound by it or subject to its application.

(70) In accordance with Articles 1 and 2 of Protocol No 22 on the position of Denmark, annexed to the TEU and to the TFEU, Denmark is not taking part in the adoption of this Directive and is not bound by it or subject to its application.

(71) This Directive aims to amend and expand the provisions of Directive 2008/99/EC. Since the amendments to be made are substantial in number and nature, Directive 2008/99/EC, should, in the interests of clarity, be replaced in its entirety in relation to the Member States bound by this Directive.

(72) Directive 2005/35/EC of the European Parliament and of the Council ([17]) was supplemented by Directive 2009/123/EC with provisions on criminal offences and penalties for ship-source discharges of polluting substances. Such offences and penalties should fall within the scope of this Directive. Therefore, for Member States bound by this Directive, Directive 2009/123/EC should be replaced. That replacement should be without prejudice to the obligation of those Member States with regard to the date for transposition of that Directive into national law. Accordingly, with regard to the Member States bound by this Directive, references to those provisions of Directive 2005/35/EC added or replaced by Directive 2009/123/EC should be construed as references to this Directive. Member States not bound by this Directive should remain bound by Directive 2005/35/EC as amended by Directive 2009/123/EC.

(73) Since the objectives of this Directive, namely to provide common definitions of environmental criminal offences and the availability of effective, dissuasive and proportionate criminal penalties for serious offences, cannot be sufficiently achieved by the Member States but can rather, by reason, inter alia, of the cross-border damage which can be caused to the environment by the unlawful conduct concerned and by reason of scale and effects of the response needed, be better achieved at Union level, the Union may adopt measures, in accordance with the principle of subsidiarity as set out in Article 5 TEU. In accordance with the principle of proportionality as set out in that Article, this Directive does not go beyond what is necessary to achieve those objectives.

(74) The obligations under this Directive are without prejudice to Union law on procedural rights in criminal proceedings and Member States should ensure that the procedural rights of suspected or accused persons in criminal proceedings are fully respected.

(75) This Directive respects the fundamental rights and observes the principles as recognised in particular by the Charter, including the protection of personal data, the freedom of expression and information, the freedom to conduct a business, the right to an effective remedy and to a fair trial, the presumption of innocence and right of defence, the principles of legality and

proportionality of criminal offences and penalties, and the right not to be tried or punished twice in criminal proceedings for the same offence. This Directive seeks to ensure full respect for those rights and principles and should be implemented accordingly,

HAVE ADOPTED THIS DIRECTIVE:

Article 1. **Subject matter**

This Directive establishes minimum rules with regard to the definition of criminal offences and penalties in order to protect the environment more effectively, as well as with regard to measures to prevent and combat environmental crime and to effectively enforce Union environmental law.

Article 2. **Definitions**

1. The terms used in this Directive for the purpose of describing conduct listed in Article 3(2) shall be construed, where applicable, in accordance with definitions provided for in Union law as referred to in Article 3(1), point (a).

2. For the purposes of this Directive, the following definitions apply:

(a) 'legal person' means any legal entity having such status under the applicable national law, except for States or public bodies exercising State authority and for public international organisations;

(b) 'habitat within a protected site' means any habitat of species for which an area is classified as a special protection area pursuant to Article 4(1) or (2) of Directive 2009/147/EC, or any natural habitat or habitat of species for which a site is designated as a special area of conservation in accordance with Article 4(4) of Directive 92/43/EEC or for which a site is listed as a site of Community importance in accordance with Article 4(2) of Directive 92/43/EEC;

(c) 'ecosystem' means a dynamic complex of plant, animal, fungi and microorganism communities and their non-living environment, interacting as a functional unit, and includes habitat types, habitats of species and species populations.

Article 3. **Criminal offences**

1. Member States shall ensure that conduct listed in paragraphs 2 and 3 of this Article, where it is intentional, and conduct referred to in paragraph 4 of this Article, where it is carried out with at least serious negligence, constitutes a criminal offence where that conduct is unlawful.

For the purpose of this Directive, conduct shall be unlawful where it breaches:

(a) Union law which contributes to pursuit of one of the objectives of the Union's policy on the environment as set out in Article 191(1) TFEU; or

(b) a law, regulation or administrative provision of a Member State, or a decision taken by a competent authority of a Member State, which gives effect to the Union law referred to in point (a).

Such conduct shall be unlawful even where it is carried out under an authorisation issued by a competent authority of a Member State if such authorisation was obtained fraudulently or by corruption, extortion or coercion, or if such authorisation is in manifest breach of relevant substantive legal requirements.

2. Member States shall ensure that the following conduct constitutes a criminal offence where it is unlawful and intentional:

(a) the discharge, emission or introduction of a quantity of materials or substances, energy or ionising radiation, into air, soil or water which causes or is likely to cause the death of, or serious injury to, any person or substantial damage to the quality of air, soil or water, or substantial damage to an ecosystem, animals or plants;

(b) the placing on the market, in breach of a prohibition or another requirement aimed at protecting the environment, of a product the use of which on a larger scale, namely the use of the product by several users, regardless of their number, results in the discharge, emission or introduction of a quantity of materials or substances, energy or ionising radiation into air, soil or water and causes or is likely to cause the death of, or serious injury to, any person or substantial damage to the quality of air, soil or water, or substantial damage to an ecosystem, animals or plants;

(c) the manufacture, placing or making available on the market, export or use of substances, whether on their own, in mixtures or in articles, including their incorporation into articles, where such conduct causes or is likely to cause the death of, or serious injury to, any person, substantial damage to the quality of air, soil or water, or substantial damage to an ecosystem, animals or plants and:

(i) is restricted pursuant to Title VIII of and Annex XVII to Regulation (EC) No 1907/2006 of the European Parliament and of the Council ([18]);

(ii) is prohibited pursuant to Title VII of Regulation (EC) No 1907/2006;

(iii) is not in compliance with Regulation (EC) No 1107/2009 of the European Parliament and of the Council ([19]);

(iv) is not in compliance with Regulation (EU) No 528/2012 of the European Parliament and of the Council ([20]);

(v) is not in compliance with Regulation (EC) No 1272/2008 of the European Parliament and of the Council ([21]); or

(vi) is prohibited pursuant to Annex I to Regulation (EU) 2019/1021 of the European Parliament and of the Council ([22]);

(d) the manufacture, use, storage, import or export of mercury, mercury compounds, mixtures of mercury, and mercury-added products where such conduct is not in compliance with the requirements set out in Regulation (EU) 2017/852 of the European Parliament and of the Council ([23]) and causes or is likely to cause the death of, or serious injury to, any person, substantial damage to the quality of air, soil or water, or substantial damage to an ecosystem, animals or plants;

(e) the execution of projects within the meaning of Article 1(2)(a), as referred to in Article 4(1) and (2), of Directive 2011/92/EU of the European Parliament and of the Council ([24]), where such conduct is carried out without a development consent and causes or is likely to cause substantial damage to the quality of air or soil, or the quality or status of water, or substantial damage to an ecosystem, animals or plants;

(f) the collection, transport or treatment of waste, the supervision of such operations and the after-care of disposal sites, including action taken as a dealer or a broker, where such conduct:

(i) concerns hazardous waste as defined in Article 3(2) of Directive 2008/98/EC of the European Parliament and of the Council ([25]) and it concerns a non-negligible quantity of such waste; or

(ii) concerns waste other than that referred to in point (i) and causes or is likely to cause the death of, or serious injury to, any person or substantial damage to the quality of air, soil or water, or substantial damage to an ecosystem, animals or plants;

(g) the shipment of waste, within the meaning of Article 2, point (26), of Regulation (EU) 2024/1157 of the European Parliament and of the Council ([26]), where such conduct concerns a non-negligible quantity, whether executed in a single shipment or in several shipments which appear to be linked;

(h) the recycling of ships falling within the scope of Regulation (EU) No 1257/2013, where such conduct is not in compliance with the requirements referred to in Article 6(2), point (a), of that Regulation;

(i) the ship-source discharge of polluting substances falling within the scope of Article 3 of Directive 2005/35/EC into any area referred to in Article 3(1) of that Directive, except where such ship-source discharge satisfies the conditions for exceptions set out in Article 5 of that Directive, which causes or is likely to cause deterioration in the quality of water or damage to the marine environment;

(j) the operation or closure of an installation in which a dangerous activity is carried out or in which dangerous substances or mixtures are stored or used, where such conduct and such dangerous activity, substance or mixture fall within the scope of Directive 2012/18/EU of the European Parliament and of

the Council ([27]) or of Directive 2010/75/EU of the European Parliament and of the Council ([28]), and such conduct causes or is likely to cause the death of, or serious injury to, any person or substantial damage to the quality of air, soil or water, or substantial damage to an ecosystem, animals or plants;

(k) the construction, operation and dismantling of an installation, where such conduct and such an installation fall within the scope of Directive 2013/30/EU of the European Parliament and of the Council ([29]), and such conduct causes or is likely to cause the death of, or serious injury to, any person or substantial damage to the quality of air, soil or water, or substantial damage to an ecosystem, animals or plants;

(l) the manufacture, production, processing, handling, use, holding, storage, transport, import, export or disposal of radioactive material or radioactive substances, where such conduct and such a material or substances fall within the scope of Council Directives 2013/59/Euratom ([30]), 2014/87/Euratom ([31]) or 2013/51/Euratom ([32]), and such conduct causes or is likely to cause the death of, or serious injury, to any person or substantial damage to the quality of air, soil or water, or substantial damage to an ecosystem, animals or plants;

(m) the abstraction of surface water or groundwater within the meaning of Directive 2000/60/EC of the European Parliament and of the Council ([33]), where such conduct causes or is likely to cause substantial damage to the ecological status or ecological potential of surface water bodies or to the quantitative status of groundwater bodies;

(n) the killing, destruction, taking of, possession, sale or offering for sale of a specimen or specimens of a species of wild fauna or flora listed in Annex IV, or in Annex V where species in that Annex are subject to the same measures as those adopted for species in Annex IV, to Council Directive 92/43/EEC ([34]) and of a specimen or specimens of the species referred to in Article 1 of Directive 2009/147/EC of the European Parliament and of the Council ([35]), except where such conduct concerns a negligible quantity of such specimens;

(o) the trade of a specimen or specimens, or parts or derivatives thereof, of a species of wild fauna or flora, listed in Annexes A and B to Council Regulation (EC) No 338/97 ([36]), and import of a specimen or specimens, or parts or derivatives thereof, of such species listed in Annex C to that Regulation, except where such conduct concerns a negligible quantity of such specimens;

(p) the placing or making available on the Union market or the export from the Union market of relevant commodities or relevant products, in breach of the prohibition set out in Article 3 of Regulation (EU) 2023/1115, except where such conduct concerns a negligible quantity;

(q) any conduct which causes the deterioration of a habitat within a protected site, or the disturbance of animal species listed in Annex II, point (a), to Directive 92/43/EEC within a protected site, within the meaning of Article 6(2) of that

Directive, where such deterioration or disturbance is significant;

(r) the bringing into the territory of the Union, placing on the market, keeping, breeding, transporting, using, exchanging, permitting to reproduce, growing or cultivating, releasing into the environment, or the spreading of invasive alien species of Union concern, where such conduct breaches:

(i) restrictions set out in Article 7(1) of Regulation (EU) No 1143/2014 of the European Parliament and of the Council ([37]) and causes or is likely to cause the death of, or serious injury to, any person or substantial damage to the quality of air, soil or water, or substantial damage to an ecosystem, animals or plants; or

(ii) a condition of a permit issued under Article 8 of Regulation (EU) No 1143/2014 or of an authorisation granted under Article 9 of that Regulation and causes or is likely to cause the death of, or serious injury to, any person or substantial damage to the quality of air, soil or water, or substantial damage to an ecosystem, animals or plants;

(s) the production, placing on the market, import, export, use, or release of ozone depleting substances, whether alone or as mixtures, as referred to in Article 2, point (a), of Regulation (EU) 2024/590 of the European Parliament and of the Council ([38]), or the production, placing on the market, import, export or use of products and equipment, and parts thereof, containing ozone-depleting substances or whose functioning relies upon those substances as referred to in Article 2(b) of that Regulation;

(t) the production, placing on the market, import, export, use, or release of fluorinated greenhouse gases, whether alone or as mixtures, as referred to in Article 2, point (a), of Regulation (EU) 2024/573 of the European Parliament and of the Council ([39]) or the production, placing on the market, import, export or use of products and equipment, and parts thereof, containing fluorinated greenhouse gases or whose functioning relies upon those gases as referred to in Article 2, point (b), of that Regulation, or the putting into operation of such products and equipment.

3. Member States shall ensure that criminal offences relating to conduct listed in paragraph 2 constitute qualified criminal offences if such conduct causes:

(a) the destruction of, or widespread and substantial damage which is either irreversible or long-lasting to, an ecosystem of considerable size or environmental value or a habitat within a protected site, or

(b) widespread and substantial damage which is either irreversible or long-lasting to the quality of air, soil or water.

4. Member States shall ensure that the conduct listed in paragraph 2, points (a) to (d), points (f) and (g), points (i) to (q), point (r)(ii), and points (s) and (t), constitutes a criminal offence where that conduct is unlawful and carried out with

at least serious negligence.

5. In addition to the criminal offences relating to conduct listed in paragraph 2, Member States may, in accordance with their national law, provide for additional criminal offences in order to protect the environment.

6. Member States shall ensure that, in assessing whether the damage or likely damage is substantial, as regards conduct listed in paragraph 2, points (a) to (e), point (f)(ii), points (j) to (m), and point (r), one or more of the following elements is taken into account, where relevant:

(a) the baseline condition of the affected environment;

(b) whether the damage is long-lasting, medium-term or short-term;

(c) the extent of the damage;

(d) the reversibility of the damage.

7. Member States shall ensure that, in assessing whether conduct listed in paragraph 2, points (a) to (e), point (f)(ii), points (i) to (m), and point (r), is likely to cause damage to the quality of air or soil, or the quality or status of water, or to an ecosystem, animals or plants, one or more of the following elements is taken into account, where relevant:

(a) the conduct relates to an activity which is considered to be risky or dangerous for the environment or human health, and requires an authorisation which was not obtained or complied with;

(b) the extent to which a regulatory threshold, value or another mandatory parameter set out in Union or national law referred to in paragraph 1, second subparagraph, points (a) and (b), or in an authorisation issued for the relevant activity is exceeded;

(c) whether the material or substance is classified as dangerous, hazardous or otherwise listed as harmful to the environment or human health.

8. Member States shall ensure that in assessing whether a quantity is negligible or non-negligible for the purposes of paragraph 2, point (f)(i), and points (g), (n), (o) and (p), one or more of the following elements is taken into account, where relevant:

(a) the number of items concerned;

(b) the extent to which a regulatory threshold, value or another mandatory parameter set out in Union or national law referred to in paragraph 1, second subparagraph, points (a) and (b), is exceeded;

(c) the conservation status of the fauna or flora species concerned;

(d) the cost of restoration of the environment, where it is feasible to assess that cost.

Article 4. **Inciting, aiding and abetting, and attempt**

1. Member States shall ensure that inciting, and aiding and abetting the commission of a criminal offence covered by Article 3(2) and (3) is punishable as a criminal offence.

2. Member States shall ensure that an attempt to commit a criminal offence covered by Article 3(2), points (a) to (d), points (f) and (g), points (i) to (m), and points (o), (p), (r), (s) and (t), is punishable as a criminal offence.

Article 5. **Penalties for natural persons**

1. Member States shall take the necessary measures to ensure that criminal offences referred to in Articles 3 and 4 are punishable by effective, proportionate and dissuasive criminal penalties.

2. Member States shall take the necessary measures to ensure that:

(a) criminal offences covered by Article 3(2), points (a) to (d), and points (f), (j), (k), (l) and (r), are punishable by a maximum term of imprisonment of at least 10 years if they cause the death of any person;

(b) criminal offences covered by Article 3(3) are punishable by a maximum term of imprisonment of at least eight years;

(c) criminal offences covered by Article 3(4), where that paragraph refers to Article 3(2), points (a) to (d), and points (f), (j), (k) and (l), are punishable by a maximum term of imprisonment of at least five years if they cause the death of any person;

(d) criminal offences covered by Article 3(2), points (a) to (l), and points (p), (s) and (t), are punishable by a maximum term of imprisonment of at least five years;

(e) criminal offences covered by Article 3(2), points (m), (n), (o), (q) and (r), are punishable by a maximum term of imprisonment of at least three years.

3. Member States shall take the necessary measures to ensure that natural persons who have committed criminal offences referred to in Articles 3 and 4 may be subject to accessory criminal or non-criminal penalties or measures which may include the following:

(a) an obligation to:

(i) restore the environment within a given period, if the damage is reversible,

or

(ii) pay compensation for the damage to the environment, if the damage is irreversible or the offender is not in a capacity to carry out such restoration;

(b) fines that are proportionate to the gravity of the conduct and to the individual, financial and other circumstances of the natural person concerned and, where relevant, that are determined taking due account of the gravity and duration of the damage caused to the environment and of the financial benefits generated from the offence;

(c) exclusion from access to public funding, including tender procedures, grants, concessions and licences;

(d) disqualification from holding, within a legal person, a leading position of the same type used for committing the offence;

(e) withdrawal of permits and authorisations to pursue activities that resulted in the relevant criminal offence;

(f) temporary bans on running for public office;

(g) where there is a public interest, following a case-by-case assessment, publication of all or part of the judicial decision that relates to the criminal offence committed and the penalties or measures imposed, which may include the personal data of convicted persons only in duly justified exceptional cases.

Article 6. **Liability of legal persons**

1. Member States shall ensure that legal persons can be held liable for criminal offences referred to in Articles 3 and 4 where such offences have been committed for the benefit of those legal persons by any person who has a leading position within the legal person concerned, acting either individually or as part of an organ of that legal person, based on:

(a) a power of representation of the legal person;

(b) an authority to take decisions on behalf of the legal person; or

(c) an authority to exercise control within the legal person.

2. Member States shall take the necessary measures to ensure that legal persons can be held liable where the lack of supervision or control by a person referred to in paragraph 1 has made possible the commission of a criminal offence referred to in Articles 3 and 4 for the benefit of the legal person by a person under its authority.

3. Liability of legal persons under paragraphs 1 and 2 of this Article shall not preclude criminal proceedings against natural persons who commit, incite or are accessories to the criminal offences referred to in Articles 3 and 4.

Article 7. **Penalties for legal persons**

1. Member States shall take the necessary measures to ensure that a legal person held liable pursuant to Article 6(1) or (2) is punishable by effective, proportionate and dissuasive criminal or non-criminal penalties or measures.

2. Member States shall take the necessary measures to ensure that penalties or measures for legal persons held liable pursuant to Article 6(1) or (2) for the criminal offences referred to in Articles 3 and 4 shall include criminal or non-criminal fines and may include other criminal or non-criminal penalties or measures, such as:

(a) an obligation to:

  (i) restore the environment within a given period, if the damage is reversible, or

  (ii) pay compensation for the damage to the environment, if the damage is irreversible or the offender is not in a capacity to carry out such restoration;

(b) exclusion from entitlement to public benefits or aid;

(c) exclusion from access to public funding, including tender procedures, grants, concessions and licences;

(d) temporary or permanent disqualification from the practice of business activities;

(e) withdrawal of permits and authorisations to pursue activities that resulted in the relevant criminal offence;

(f) placing under judicial supervision;

(g) judicial winding-up;

(h) closure of establishments used for committing the offence;

(i) an obligation to establish due diligence schemes for enhancing compliance with environmental standards;

(j) where there is a public interest, publication of all or part of the judicial decision relating to the criminal offence committed and the penalties or measures imposed, without prejudice to rules on privacy and the protection of personal data.

3. Member States shall take the necessary measures to ensure that, at least for legal persons held liable pursuant to Article 6(1), criminal offences covered by Article 3(2) are punishable by criminal or non-criminal fines, the amount of which shall be proportionate to the gravity of the conduct and to the individual, financial and other circumstances of the legal person concerned. Member States shall take the necessary measures to ensure that the maximum level of such fines is not less

than:

(a) for criminal offences covered by Article 3(2), points (a) to (l), and points (p), (s) and (t):

(i) 5 % of the total worldwide turnover of the legal person, either in the business year preceding that in which the offence was committed, or in the business year preceding that of the decision to impose the fine, or

(ii) an amount corresponding to EUR 40 000 000;

(b) for criminal offences covered by Article 3(2), points (m), (n), (o), (q) and (r):

(i) 3 % of the total worldwide turnover of the legal person, either in the business year preceding that in which the offence was committed, or in the business year preceding that of the decision to impose the fine, or

(ii) an amount corresponding to EUR 24 000 000.

Member States may establish rules for cases where it is not possible to determine the amount of the fine on the basis of the total worldwide turnover of the legal person in the business year preceding that in which the offence was committed, or in the business year preceding that of the decision to impose the fine.

4. Member States shall take the necessary measures to ensure that legal persons held liable pursuant to Article 6 for the criminal offences covered by Article 3(3) are punishable by more severe criminal or non-criminal penalties or measures than those applicable for the criminal offences covered by Article 3(2).

Article 8. **Aggravating circumstances**

To the extent that the following circumstances do not form part of the constituent elements of the criminal offences referred to in Article 3, Member States shall take the necessary measures to ensure that, in relation to the relevant criminal offences referred to in Articles 3 and 4, one or more of the following circumstances can, in accordance with national law, be regarded as an aggravating circumstance:

(a) the offence caused the destruction of, or irreversible or long-lasting substantial damage to, an ecosystem;

(b) the offence was committed in the framework of a criminal organisation within the meaning of Council Framework Decision 2008/841/JHA ([40]);

(c) the offence involved the use by the offender of false or forged documents;

(d) the offence was committed by a public official when performing his or her duties;

(e) the offender has previously been convicted by a final judgment of offences of the same nature as those referred to in Article 3 or 4;

(f) the offence generated or was expected to generate substantial financial benefits, or avoided substantial expenses, directly or indirectly, to the extent

that such benefits or expenses can be determined;

(g) the offender destroyed evidence, or intimidated witnesses or complainants;

(h) the offence was committed within an area classified as a special protection area pursuant to Article 4(1) or (2) of Directive 2009/147/EC, or a site designated as a special area of conservation in accordance with Article 4(4) of Directive 92/43/EEC or a site listed as site of Community importance in accordance with Article 4(2) of Directive 92/43/EEC.

The aggravating circumstance referred to in point (a) of this Article shall not apply to the criminal offences covered by Article 3(3).

Article 9. **Mitigating circumstances**

Member States shall take the necessary measures to ensure that, in relation to the relevant criminal offences referred to in Articles 3 and 4, one or more of the following circumstances can, in accordance with national law, be regarded as a mitigating circumstance:

(a) the offender restores the environment to its previous condition, where such restoration is not an obligation under Directive 2004/35/EC, or, before the start of a criminal investigation, takes steps to minimise the impact and extent of the damage or remediates the damage;

(b) the offender provides the administrative or judicial authorities with information which they would not otherwise have been able to obtain, helping them to:

(i) identify or bring to justice other offenders;

(ii) find evidence.

Article 10. **Freezing and confiscation**

Member States shall take the necessary measures to enable the tracing, identifying, freezing and confiscation of instrumentalities and proceeds from the criminal offences referred to in Articles 3 and 4.

Member States bound by Directive 2014/42/EU of the European Parliament and of the Council ([41]) shall take the measures referred to in the first paragraph in accordance with that Directive.

Article 11. **Limitation periods**

1. Member States shall take the necessary measures to provide for a limitation period that enables the investigation, prosecution, trial and adjudication of criminal offences referred to in Articles 3 and 4 for a sufficient period of time after the commission of those criminal offences, in order for those criminal offences to be tackled effectively.

Member States shall take the necessary measures to provide for a limitation period

that enables the enforcement of penalties imposed following a final conviction for criminal offences referred to in Articles 3 and 4 for a sufficient period of time after that conviction.

2. The limitation period referred to in paragraph 1, first subparagraph, shall be as follows:

(a) at least 10 years from the commission of a criminal offence punishable by a maximum term of imprisonment of at least 10 years;

(b) at least five years from the commission of a criminal offence punishable by a maximum term of imprisonment of at least five years;

(c) at least three years from the commission of a criminal offence punishable by a maximum term of imprisonment of at least three years.

3. The limitation period referred to in paragraph 1, second subparagraph, shall be as follows:

(a) at least 10 years from the date of the final conviction in the following cases:

(i) a penalty of imprisonment of more than five years, or alternatively

(ii) a penalty of imprisonment for a criminal offence punishable by a maximum term of imprisonment of at least 10 years;

(b) at least five years from the date of the final conviction in the following cases:

(i) a penalty of imprisonment of more than one year, or alternatively

(ii) a penalty of imprisonment for a criminal offence punishable by a maximum term of imprisonment of at least five years; and

(c) at least three years from the date of the final conviction in the following cases:

(i) a penalty of imprisonment of up to one year, or alternatively

(ii) a penalty of imprisonment for a criminal offence punishable by a maximum term of imprisonment of at least three years.

4. By way of derogation from paragraphs 2 and 3, Member States may establish a limitation period that is shorter than 10 years, but not shorter than five years, provided that such limitation period may be interrupted or suspended in the event of specified acts.

Article 12. **Jurisdiction**

1. Member State shall take the necessary measures to establish its jurisdiction over the criminal offences referred to in Articles 3 and 4 where:

(a) the offence was committed in whole or in part within its territory;

Each

(b) the offence was committed on board a ship or an aircraft registered in the Member State concerned, or flying its flag;

(c) the damage which is one of the constituent elements of the offence occurred on its territory; or

(d) the offender is one of its nationals.

2. A Member State shall inform the Commission where it decides to extend its jurisdiction to one or more criminal offences referred to in Articles 3 and 4 which have been committed outside its territory, where:

(a) the offender is a habitual resident in its territory;

(b) the offence is committed for the benefit of a legal person established in its territory;

(c) the offence is committed against one of its nationals or its habitual residents; or

(d) the offence has created a severe risk for the environment on its territory.

Where a criminal offence referred to in Articles 3 and 4 falls within the jurisdiction of more than one Member State, those Member States shall cooperate to determine which Member State is to conduct the criminal proceedings. The matter shall, where appropriate and in accordance with Article 12(2) of Council Framework Decision 2009/948/JHA ([42]), be referred to Eurojust.

3. In cases referred to in paragraph 1, points (c) and (d), Member States shall take the necessary measures to ensure that the exercise of their jurisdiction is not subject to the condition that a prosecution can be initiated only following a denunciation from the State of the place where the criminal offence was committed.

Article 13. **Investigative tools**

Member States shall take the necessary measures to ensure that effective and proportionate investigative tools are available for investigating or prosecuting criminal offences referred to in Articles 3 and 4. Where appropriate, those tools shall include special investigative tools, such as those used in combatting organised crime or in other serious crime cases.

Article 14. **Protection of persons who report environmental criminal offences or assist the investigation thereof**

Without prejudice to Directive (EU) 2019/1937, Member States shall take the necessary measures to ensure that any persons reporting criminal offences

referred to in Articles 3 and 4 of this Directive, providing evidence or otherwise cooperating with competent authorities, have access to support and assistance measures in the context of criminal proceedings, in accordance with national law.

Article 15. **Publication of information in the public interest and access to justice for the public concerned**

Member States shall ensure that persons affected or likely to be affected by the criminal offences referred to in Articles 3 and 4 of this Directive and persons having a sufficient interest or maintaining the impairment of a right, as well as non-governmental organisations that promote environmental protection and meet requirements under national law, have appropriate procedural rights in proceedings concerning those offences, where such procedural rights for the public concerned exist in the

Member State in proceedings concerning other criminal offences, for instance as a civil party. In such cases, Member States shall also ensure, in accordance with their national law, that the information on the progress of the proceedings is shared with the public concerned, where that is done in proceedings concerning other criminal offences.

Article 16. **Prevention**

Member States shall take appropriate measures, such as information and awareness-raising campaigns targeting relevant stakeholders from the public and private sector, as well as research and education programmes, which aim to reduce environmental criminal offences and the risk of environmental crime. Where appropriate, Member States shall act in cooperation with such stakeholders.

Article 17. **Resources**

Member States shall ensure that national authorities which detect, investigate, prosecute or adjudicate environmental criminal offences have a sufficient number of qualified staff and sufficient financial, technical and technological resources for the effective performance of their functions related to the implementation of this Directive.

Member States shall, taking into account the constitutional traditions and structure of their legal system, as well as other national circumstances, assess the need to increase the level of specialisation of those authorities in the area of environmental criminal law, in accordance with national law.

Article 18. **Training**

Without prejudice to judicial independence and differences in the organisation of the judiciary across the Union, Member States shall take necessary measures to ensure that specialised regular training is provided to judges, prosecutors, police and judicial staff and to competent authorities' staff involved in criminal

proceedings and investigations with regard to the objectives of this Directive and appropriate to the functions of such judges, prosecutors, police and judicial staff and competent authorities' staff.

Article 19. Coordination and cooperation between competent authorities within a Member State

Member States shall take the necessary measures to establish appropriate mechanisms for coordination and cooperation at strategic and operational levels among all their competent authorities involved in the prevention of and the fight against environmental criminal offences. Such mechanisms shall be aimed at least at:

(a) ensuring common priorities and understanding of the relationship between criminal and administrative enforcement;

(b) exchange of information for strategic and operational purposes, within the limits set out in applicable Union and national law;

(c) consultation in individual investigations, within the limits set out in applicable Union and national law;

(d) the exchange of best practices;

(e) providing assistance to European networks of practitioners working on matters relevant to combatting environmental criminal offences and related infringements.

The mechanisms referred to in the first paragraph may take the form of specialised coordination bodies, memoranda of understanding between competent authorities, national enforcement networks and joint training activities.

Article 20. Cooperation between Member States and the Commission, and Union bodies, offices or agencies

Where environmental criminal offences are suspected to be of a cross-border nature, the competent authorities of the Member States concerned shall consider referring the information related to those offences to appropriate competent bodies.

Without prejudice to the rules on cross-border cooperation and mutual legal assistance in criminal matters, the Member States, Eurojust, Europol, the European Public Prosecutor's Office, the European Anti-Fraud Office and the Commission shall, within their respective competences, cooperate with each other in the fight against the criminal offences referred to in Articles 3 and 4.

To that end, Eurojust shall, where appropriate, provide the technical and operational assistance needed by the competent national authorities to facilitate coordination of their investigations. The Commission may, where appropriate, provide assistance.

Article 21. **National strategy**

1. Member States shall establish and publish a national strategy on combatting environmental criminal offences by 21 May 2027.

Member States shall take measures to implement their national strategy without undue delay. The national strategy shall address at least the following:

(a) the objectives and priorities of national policy in the area of environmental criminal offences, including in cross-border cases, and arrangements for regular evaluation of whether they are being attained;

(b) the roles and responsibilities of all the competent authorities involved in combatting environmental criminal offences, including as regards coordination and cooperation between the national competent authorities as well as with the competent Union bodies and as regards providing assistance to European networks working on matters directly relevant to combatting those offences, including in cross-border cases;

(c) how specialisation of enforcement professionals will be supported, an estimation of the resources allocated to combat environmental crime and an evaluation of future needs in that regard.

2. Member States shall ensure that their national strategy is reviewed and updated at regular intervals which are no longer than five years, on the basis of a risk-analysis-based approach, in order to take account of relevant developments and trends and related threats regarding environmental crime.

Article 22. **Statistical data**

1. Member States shall ensure that a system is in place for the recording, production and provision of anonymised statistical data on the reporting, investigative and judicial stages in relation to the criminal offences referred to in Articles 3 and 4 in order to monitor the effectiveness of their measures to combat environmental criminal offences.

2. The statistical data referred to in paragraph 1 shall, as a minimum, include existing data on:

(a) the number of criminal offences registered and adjudicated by the Member States;

(b) the number of dismissed court cases, including on the grounds of expiry of the limitation period for the criminal offence concerned;

(c) the number of natural persons that are:

  (i) prosecuted,

  (ii) convicted;

(d) the number of legal persons that are:

(i) prosecuted,

(ii) convicted or fined;

(e) the types and levels of penalties imposed.

3. Member States shall ensure that a consolidated review of their statistics is published at least every three years.

4. Member States shall annually transmit to the Commission the statistical data referred to in paragraph 2 of this Article in the standard format referred to in Article 23.

5. The Commission shall, at least every three years, publish a report based on the statistical data transmitted by the Member States. The report shall be published for the first time three years after the standard format referred to in Article 23 has been established.

Article 23. **Implementing powers**

1. By 21 May 2027, the Commission shall establish, by means of implementing acts, a standard, easily accessible and comparable format for the transmission of statistical data referred to in Article 22(4). Those implementing acts shall be adopted in accordance with the examination procedure referred to in Article 24(2).

2. The standard format for the transmission of statistical data shall comprise the following elements:

(a) a classification of environmental criminal offences;

(b) counting units;

(c) a reporting format.

A common understanding of the elements referred to in the first subparagraph shall be ensured.

Article 24. **Committee procedure**

1. The Commission shall be assisted by a committee. That committee shall be a committee within the meaning of Regulation (EU) No 182/2011.

2. Where reference is made to this paragraph, Article 5 of Regulation (EU) No 182/2011 shall apply.

3. Where the committee delivers no opinion, the Commission shall not adopt the draft implementing act and Article 5(4), third subparagraph, of Regulation (EU) No 182/2011 shall apply.

Article 25. **Evaluation, reporting and review**

1. By 21 May 2028, the Commission shall submit a report to the European Parliament and to the Council assessing the extent to which the Member States have taken the necessary measures to comply with this Directive. Member States shall provide the Commission with the necessary information for the preparation of that report.

2. By 21 May 2031, the Commission shall carry out an evaluation of the impact of this Directive addressing the need to update the list of environmental criminal offences referred to in Articles 3 and 4 and submit a report to the European Parliament and to the Council. Member States shall provide the Commission with necessary information for the preparation of that report, including a summary of the implementation of this Directive and actions taken in accordance with Articles 16 to 21, and statistical data, with particular attention given to cross-border cooperation. Where necessary, that report shall be accompanied by a legislative proposal.

3. The Commission shall regularly consider if there is a need to amend the criminal offences covered by Article 3(2).

Article 26. **Replacement of Directive 2008/99/EC**

Directive 2008/99/EC is replaced with regard to the Member States bound by this Directive, without prejudice to the obligations of those Member States with regard to the date for transposition of that Directive into national law. With regard to the Member States bound by this Directive, references to Directive 2008/99/EC shall be construed as references to this Directive. As regards Member States not bound by this Directive, they shall remain bound by Directive 2008/99/EC.

Article 27. **Replacement of Directive 2009/123/EC**

Directive 2009/123/EC shall be replaced with regard to the Member States bound by this Directive, without prejudice to the obligations of those Member States with regard to the date for transposition of that Directive.

With regard to the Member States bound by this Directive, references to those provisions of Directive 2005/35/EC added or replaced by Directive 2009/123/EC shall be construed as references to this Directive.

Member States not bound by this Directive shall remain bound by Directive 2005/35/EC as amended by Directive 2009/123/EC.

Article 28. **Transposition**

1. Member States shall bring into force the laws, regulations and administrative provisions necessary to comply with this Directive by 21 May 2026. They shall immediately inform the Commission thereof.

When Member States adopt those measures, they shall contain a reference to this

Directive or shall be accompanied by such reference on the occasion of their official publication. The methods of making such reference shall be laid down by Member States.

2. Member States shall communicate to the Commission the text of the main measures of national law which they adopt in the field covered by this Directive.

Article 29. **Entry into force**

This Directive shall enter into force on the twentieth day following that of its publication in the *Official Journal of the European Union*.

Article 30. **Addressees**

This Directive is addressed to the Member States in accordance with the Treaties.

Done at Brussels, 11 April 2024.

For the European Parliament

The President

R. METSOLA

For the Council

The President

H. LAHBIB

([1]) OJ C 290, 29.7.2022, p. 143.

([2]) Position of the European Parliament of 27 February 2024 (not yet published in the Official Journal) and decision of the Council of 26 March 2024.

([3]) Directive 2008/99/EC of the European Parliament and of the Council of 19 November 2008 on the protection of the environment through criminal law (OJ L 328, 6.12.2008, p. 28).

([4]) Council Regulation (EC) No 1224/2009 of 20 November 2009 establishing a Union control system for ensuring compliance with the rules of the common fisheries policy, amending Regulations (EC) No 847/96, (EC) No 2371/2002, (EC) No 811/2004, (EC) No 768/2005, (EC) No 2115/2005, (EC) No 2166/2005, (EC) No 388/2006, (EC) No 509/2007, (EC) No 676/2007, (EC) No 1098/2007, (EC) No 1300/2008, (EC) No 1342/2008 and repealing Regulations (EEC) No 2847/93, (EC) No 1627/94 and (EC) No 1966/2006 (OJ L 343, 22.12.2009, p. 1).

([5]) Council Regulation (EC) No 1005/2008 of 29 September 2008 establishing a Community system to prevent, deter and eliminate illegal, unreported and unregulated fishing, amending Regulations (EEC) No 2847/93, (EC) No 1936/2001 and (EC) No 601/2004 and repealing Regulations (EC) No 1093/94 and (EC) No 1447/1999 (OJ L 286, 29.10.2008, p. 1).

([6]) Regulation (EU) No 1257/2013 of the European Parliament and of the Council

of 20 November 2013 on ship recycling and amending Regulation (EC) No 1013/2006 and Directive 2009/16/EC (OJ L 330, 10.12.2013, p. 1).

([7]) Regulation (EU) 2023/1115 of the European Parliament and of the Council of 31 May 2023 on the making available on the Union market and the export from the Union of certain commodities and products associated with deforestation and forest degradation and repealing Regulation (EU) No 995/2010 (OJ L 150, 9.6.2023, p. 206).

([8]) Directive 2004/35/EC of the European Parliament and of the Council of 21 April 2004 on environmental liability with regard to the prevention and remedying of environmental damage (OJ L 143, 30.4.2004, p. 56).

([9]) Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation) (OJ L 119, 4.5.2016, p. 1).

([10]) Directive (EU) 2016/680 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data by competent authorities for the purposes of the prevention, investigation, detection or prosecution of criminal offences or the execution of criminal penalties, and on the free movement of such data, and repealing Council Framework Decision 2008/977/JHA (OJ L 119, 4.5.2016, p. 89).

([11]) Regulation (EU) 2018/1727 of the European Parliament and of the Council of 14 November 2018 on the European Union Agency for Criminal Justice Cooperation (Eurojust), and replacing and repealing Council Decision 2002/187/JHA (OJ L 295, 21.11.2018, p. 138).

([12]) Directive (EU) 2019/1937 of the European Parliament and of the Council of 23 October 2019 on the protection of persons who report breaches of Union law (OJ L 305, 26.11.2019, p. 17).

([13]) Directive 2009/123/EC of the European Parliament and of the Council of 21 October 2009 amending Directive 2005/35/EC on ship-source pollution and on the introduction of penalties for infringements (OJ L 280, 27.10.2009, p. 52).

([14]) Directive 2012/29/EU of the European Parliament and of the Council of 25 October 2012 establishing minimum standards on the rights, support and protection of victims of crime, and replacing Council Framework Decision 2001/220/JHA (OJ L 315, 14.11.2012, p. 57).

([15]) Council Framework Decision 2009/315/JHA of 26 February 2009 on the organisation and content of the exchange of information extracted from the criminal record between Member States (OJ L 93, 7.4.2009, p. 23).

([16]) Regulation (EU) No 182/2011 of the European Parliament and of the Council of 16 February 2011 laying down the rules and general principles concerning mechanisms for control by Member States of the Commission’s exercise of implementing powers (OJ L 55, 28.2.2011, p. 13).

([17]) Directive 2005/35/EC of the European Parliament and of the Council of 7 September 2005 on ship-source pollution and on the introduction of penalties,

including criminal penalties, for pollution offences (OJ L 255, 30.9.2005, p. 11).

([18]) Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC (OJ L 396, 30.12.2006, p. 1).

([19]) Regulation (EC) No 1107/2009 of the European Parliament and of the Council of 21 October 2009 concerning the placing of plant protection products on the market and repealing Council Directives 79/117/EEC and 91/414/EEC (OJ L 309, 24.11.2009, p. 1).

([20]) Regulation (EU) No 528/2012 of the European Parliament and of the Council of 22 May 2012 concerning the making available on the market and use of biocidal products (OJ L 167, 27.6.2012, p. 1).

([21]) Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006 (OJ L 353, 31.12.2008, p. 1).

([22]) Regulation (EU) 2019/1021 of the European Parliament and of the Council of 20 June 2019 on persistent organic pollutants (OJ L 169, 25.6.2019, p. 45).

([23]) Regulation (EU) 2017/852 of the European Parliament and of the Council of 17 May 2017 on mercury, and repealing Regulation (EC) No 1102/2008 (OJ L 137, 24.5.2017, p. 1).

([24]) Directive 2011/92/EU of the European Parliament and of the Council of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment (OJ L 26, 28.1.2012, p. 1).

([25]) Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (OJ L 312, 22.11.2008, p. 3).

([26]) Regulation (EU) 2024/1157 of the European Parliament and of the Council of 11 April 2024 on shipments of waste, amending Regulations (EU) No 1257/2013 and (EU) 2020/1056 and repealing Regulation (EC) No 1013/2006 (OJ L, 2024/1157, 30.4.2024, ELI: http://data.europa.eu/eli/reg/2024/1157/oj).

([27]) Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC (OJ L 197, 24.7.2012, p. 1).

([28]) Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) (OJ L 334, 17.12.2010, p. 17).

([29]) Directive 2013/30/EU of the European Parliament and of the Council of

12 June 2013 on safety of offshore oil and gas operations and amending Directive 2004/35/EC (OJ L 178, 28.6.2013, p. 66).

([30]) Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom (OJ L 13, 17.1.2014, p. 1).

([31]) Council Directive 2014/87/Euratom of 8 July 2014 amending Directive 2009/71/Euratom establishing a Community framework for the nuclear safety of nuclear installations (OJ L 219, 25.7.2014, p. 42).

([32]) Council Directive 2013/51/Euratom of 22 October 2013 laying down requirements for the protection of the health of the general public with regard to radioactive substances in water intended for human consumption (OJ L 296, 7.11.2013, p. 12).

([33]) Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (OJ L 327, 22.12.2000, p. 1).

([34]) Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (OJ L 206, 22.7.1992, p. 7).

([35]) Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds (OJ L 20, 26.1.2010, p. 7).

([36]) Council Regulation (EC) No 338/97 of 9 December 1996 on the protection of species of wild fauna and flora by regulating trade therein (OJ L 61, 3.3.1997, p. 1).

([37]) Regulation (EU) No 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species (OJ L 317, 4.11.2014, p. 35).

([38]) Regulation (EU) 2024/590 of the European Parliament and of the Council of 7 February 2024 on substances that deplete the ozone layer, and repealing Regulation (EC) No 1005/2009 (OJ L, 2024/590, 20.2.2024, ELI: http://data.europa.eu/eli/reg/2024/590/oj).

([39]) Regulation (EU) 2024/573 of the European Parliament and of the Council of 7 February 2024 on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014 (OJ L, 2024/573, 20.2.2024, ELI: http://data.europa.eu/eli/reg/2024/573/oj).

([40]) Council Framework Decision 2008/841/JHA of 24 October 2008 on the fight against organised crime (OJ L 300, 11.11.2008, p. 42).

([41]) Directive 2014/42/EU of the European Parliament and of the Council of 3 April 2014 on the freezing and confiscation of instrumentalities and proceeds of crime in the European Union (OJ L 127, 29.4.2014, p. 39).

([42]) Council Framework Decision 2009/948/JHA of 30 November 2009 on prevention and settlement of conflicts of exercise of jurisdiction in criminal proceedings (OJ L 328, 15.12.2009, p. 42).

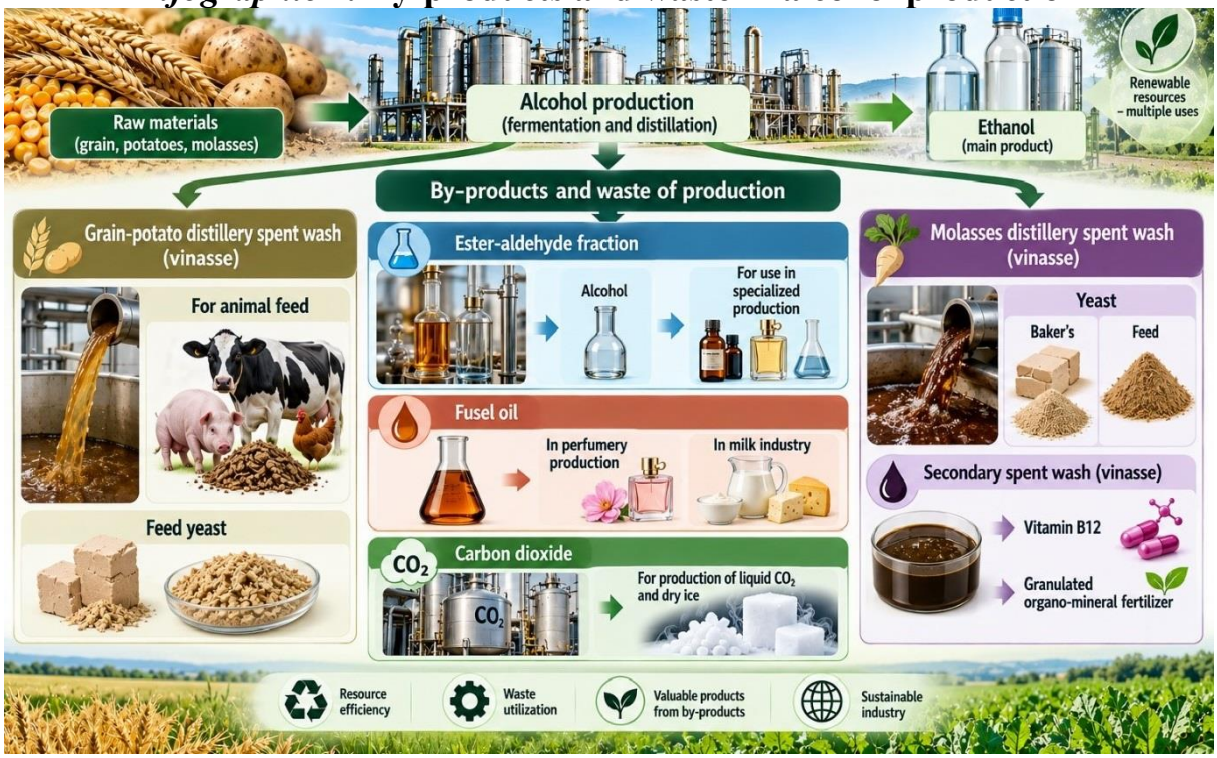
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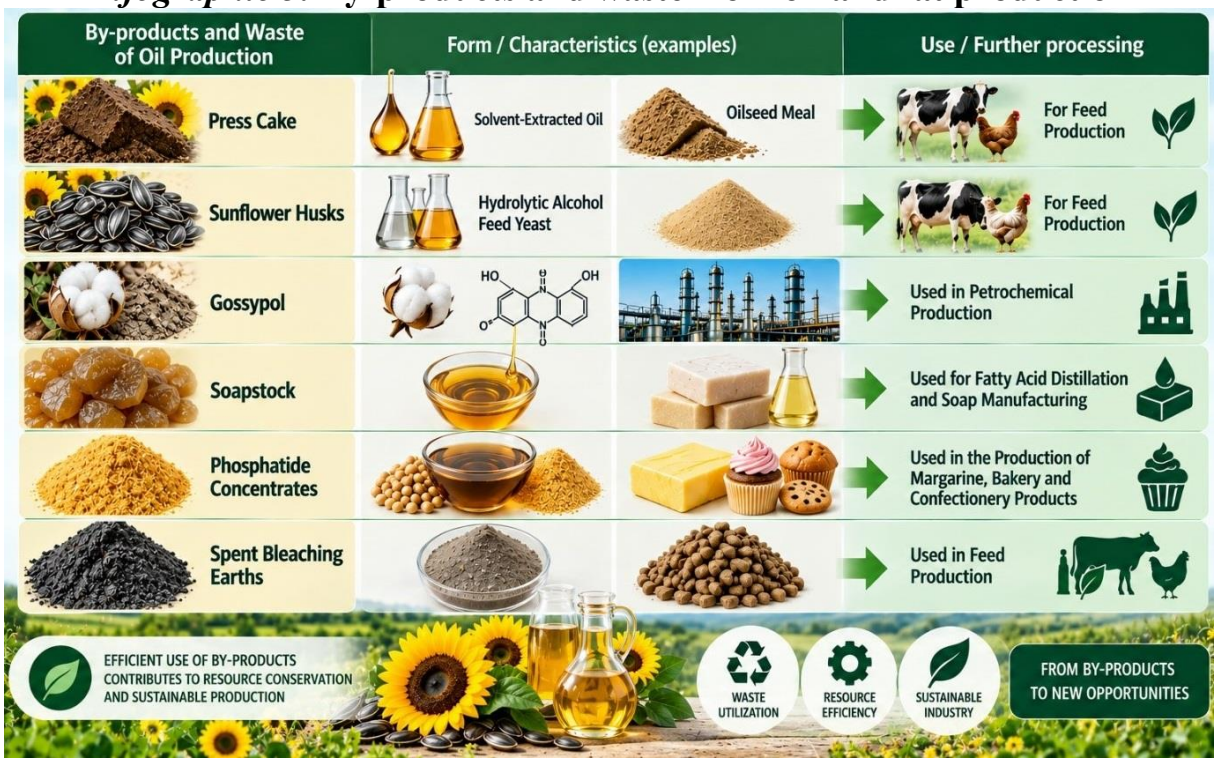
Infographic 1. **By-products and waste in the production of sugar from beets**



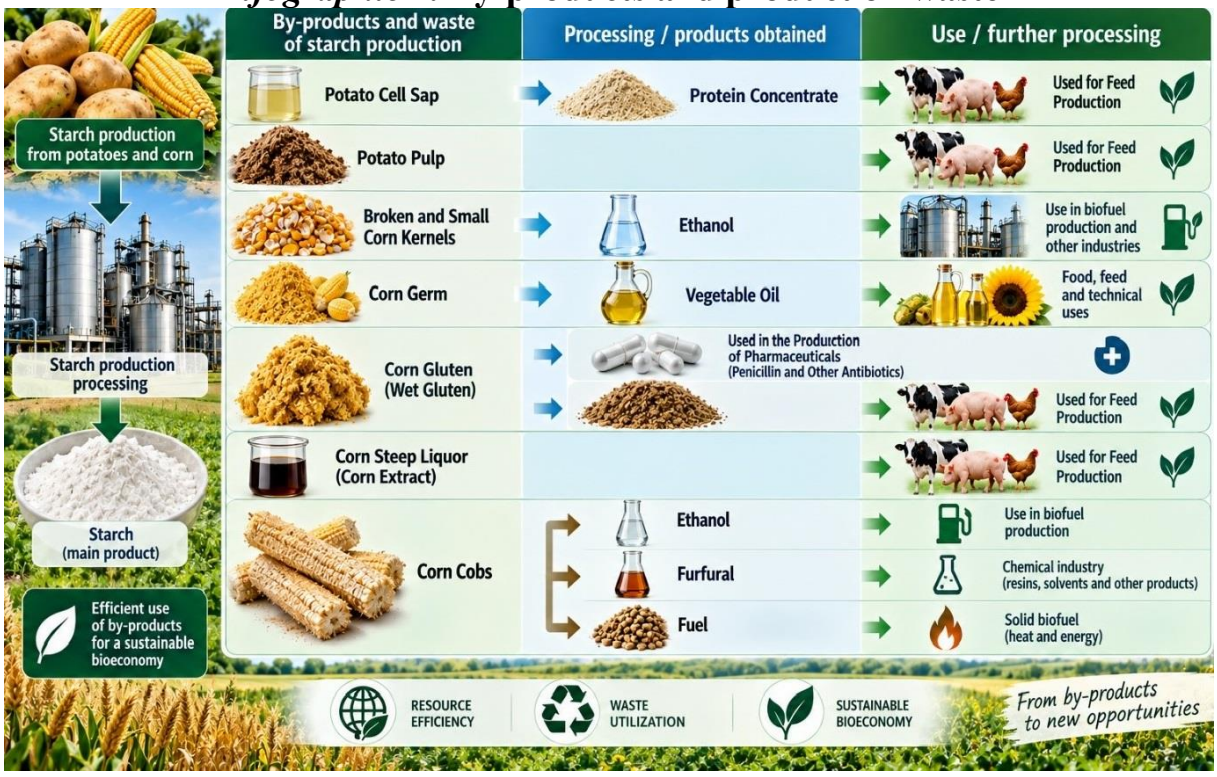
Infographic 2. **By-products and waste in alcohol production**



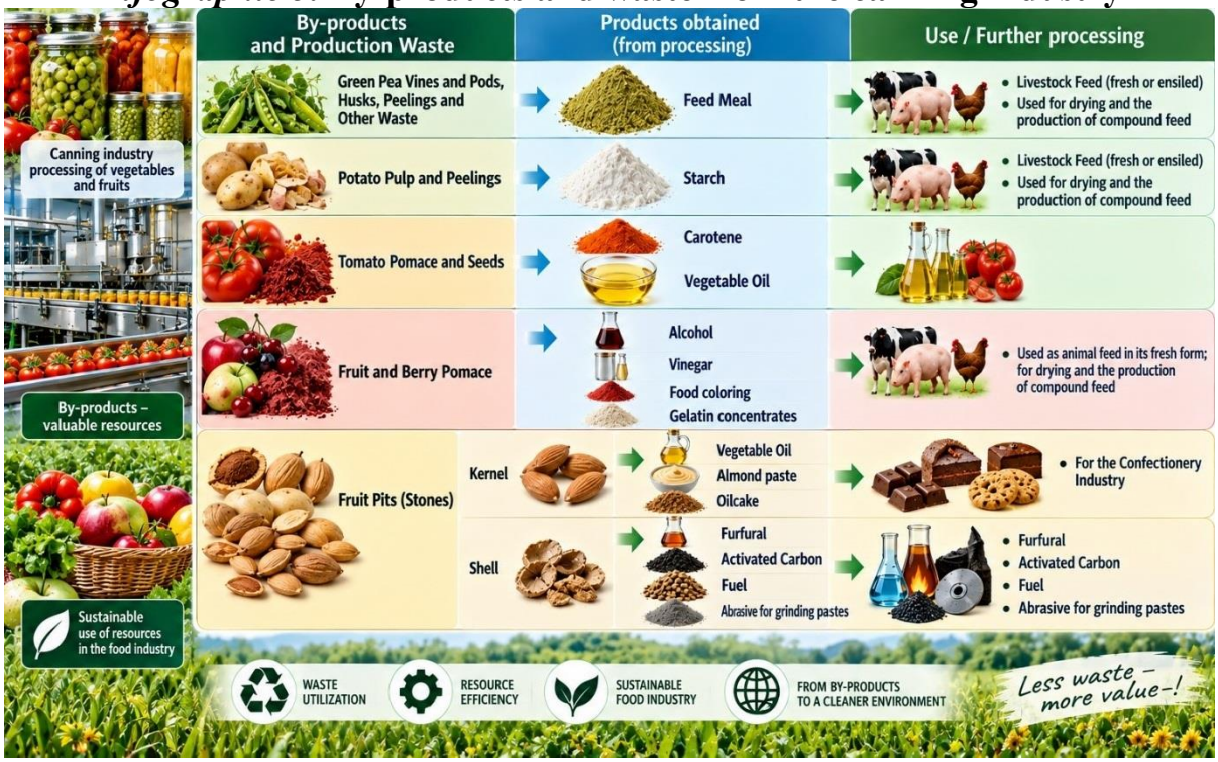
Infographic 3. **By-products and waste from oil and fat production**



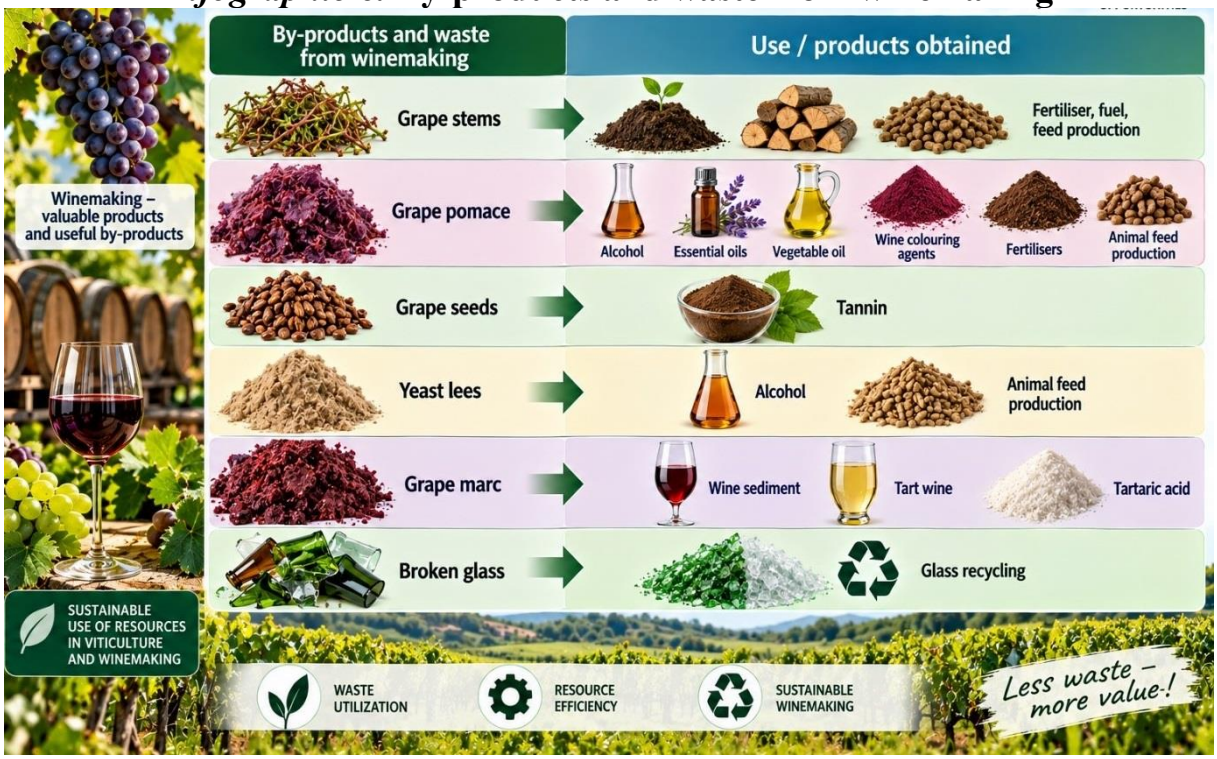
Infographic 4. **By-products and production waste**



Infographic 5. **By-products and waste from the canning industry**



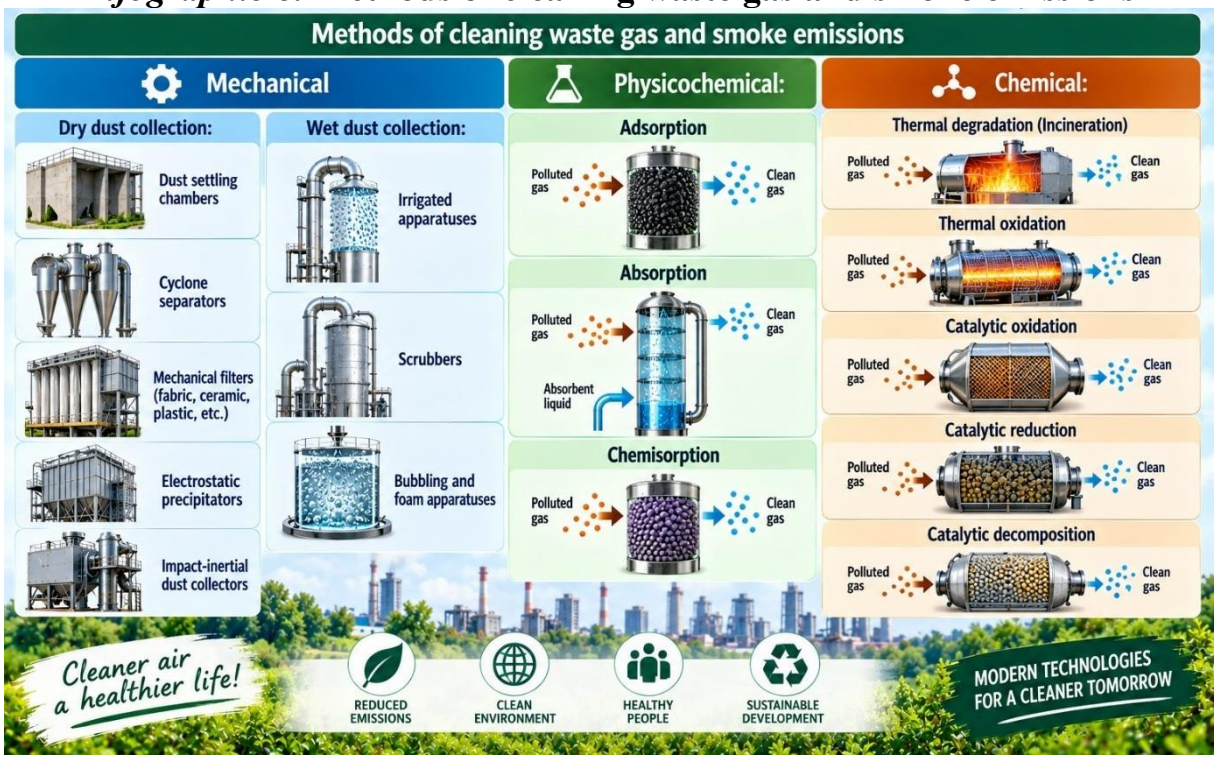
Infographic 6. **By-products and waste from winemaking**



Infographic 7. **Measures to protect atmospheric air**



Infographic 8. **Methods of cleaning waste gas and smoke emissions**



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INDUSTRIAL ECOLOGY OF PROCESSING ENTERPRISES

Textbook

Видавець ФОП Ямчинський О.В.
03150, Київ, вул. Васильківська, 32
Свідоцтво про внесення до Державного реєстру
суб'єкта видавничої справи ДК № 6554 від 26.12.2018 р.

Формат 60×8 /16. Наклад 100 пр. Ум. друк. арк. 25,4. Зам. № 720
Виготовлювач ТОВ «ЦП «КОМПРИНТ»
03150, Київ, вул. Васильківська, 32
Свідоцтво про внесення до Державного реєстру суб'єкта видавничої
справи ДК № 4131 від 04.08.2011 р.