

98. *Khlopetskyi R., Ph.D., Didukh V., D.Sc. (Tech.). Lutsk National Technical University*

### FEATURES OF NITROCELLULOSE PRODUCTION FROM OIL FLAX STEMS

Modern realities and challenges dictate new demands for raw materials to revive previously existing industries that have not been in demand for the past decades. Military expenditures are exhausting production capacities for the supply of explosive and flammable substances, creating a need to search for accessible raw materials for their further production. Long-standing practice of wars and conflicts has clearly outlined the list of explosives used to produce gunpowder – specifically nitro compounds derived from nitric acid, namely nitrocellulose. Traditionally, cotton has been considered the primary raw material for producing nitrocellulose. However, in modern Ukrainian conditions, such material is not readily available in sufficient quantities, its cultivation is not zonally adapted to the Ukrainian climate, and it requires specialized growing technologies and a narrow-profile fleet of machines for its cultivation and harvesting.

By contrast, the fiber from oil flax stems is a suitable source of cellulose for nitration. It is well-adapted for cultivation in our climate zone, does not require a large amount of specialized machinery, and its use helps solve the problem of disposing of flax retted straw, which currently presents a significant obstacle for farmers cultivating oil flax varieties.

The process of obtaining nitrocellulose from flax fiber materials is based on the interaction of cellulose with a nitrating system, which is typically based on the use of nitric acid or its salts combined with a component that acts as a dehydrating agent. Nitration is a heterogeneous esterification reaction in which the hydroxyl groups of cellulose are replaced by nitro groups ( $-\text{NO}_2$ ), forming cellulose nitrates:



The key parameters affecting this process include the concentration of the nitrating components, temperature, and the duration of nitration. The reaction is conducted under controlled temperature conditions, and the duration depends on the desired degree of nitration [1].

In the studies, a laboratory reactor with a cooling jacket, equipped with a mechanical stirrer and a thermostabilization system, was used. The reactor design ensured effective heat removal and uniform mixing of the fibrous raw material with the nitrating system, which is critically important for both safety and chemical process stability.

A specific feature of using oil flax fiber for producing nitrocellulose is the presence of a significant portion of shives, which include lignin, hemicellulose, and other non-cellulosic impurities [2]. These components significantly affect the nitration process, reducing its efficiency and uniformity. Lignin and hemicellulose have more complex and less reactive chemical structures, making their full nitration impossible and resulting in the formation of unwanted inclusions. As a result, the final product is characterized by a non-uniform distribution of nitro groups, which negatively impacts the combustion rate and stability.

Removing the shives through mechanical processing or partially destroying them helps increase the effectiveness of nitration by providing better access of active components to the cellulose fibers. This ensures a more uniform degree of nitration and higher quality of the obtained nitrocellulose. Given the chemical specifics of the process, the preparation of fibrous raw material, particularly the reduction of shive content, is an important prerequisite for obtaining high-quality nitrocellulose from flax fiber materials.

Experimental studies have confirmed that stable progression of the reaction is achieved at a temperature not exceeding  $11^\circ\text{C}$  and a holding time of up to 60 minutes. The resulting product demonstrates high flammability, making it suitable for further use in the production of smokeless powder based on nitrocellulose.

Based on the conducted research and analysis of existing publications, the relevance of maximizing the efficiency of cellulose fraction extraction from oil flax raw material by removing the shive becomes evident. To minimize energy and time expenditures, it is proposed to implement a decortication mechanism into the design of a grain harvester. This mechanism is intended to perform the function of maximal destruction of the oil flax stem structure and to be used as an interchangeable module in the traditional system for shredding strawy mass. The decortication unit can also operate in conjunction with a compact roll former for simultaneously winding

the retted flax into rolls, enabling further transportation and cleaning under centralized raw material preparation conditions for nitration.

To this end, research is being conducted to determine the optimal cross-sectional shape of the decorticator shaft teeth, as well as the configuration of the decorticator blocks with sets of shafts of different tooth profiles. As part of a design experiment, four types of decorticator shaft teeth have been developed, differing in profile shape: sinusoidal – for gentle feeding and uniform shive abrasion; involute – for aggressive action on the stems; triangular – for high shredding intensity; and trapezoidal spline-shaped – for greater strength and uniform intermeshing of rollers. The types of such toothed engagements of the decorticator rollers are shown in Figure 1.

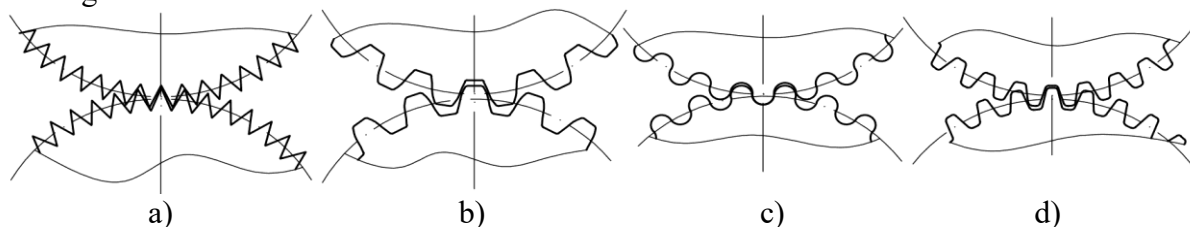


Fig. 1. Types of gear engagements of decorticator rollers:

- a) – triangular tooth profile; b) – involute tooth profile; c) – sinusoidal tooth profile;  
d) – trapezoidal tooth profile.

All rollers are manufactured as individual modules with a length of 100 mm, each featuring through-holes for mounting on a 30 mm drive shaft, along with an additional 8 mm pin for torque transmission. The design allows for length extension by sequentially mounting interconnected blocks onto a single shaft, with subsequent fixation using threaded rods and wedge-shaped inserts. These inserts ensure precise alignment between adjacent rollers and guarantee synchronous rotation.

Special attention is given to the transportation and storage of the resulting flax straw. After passing through the decortication module, the material is automatically fed into a compact roll-former integrated into the outlet section of the mechanism. This roll-former produces dense field-ready rolls, significantly simplifying logistics, minimizing material losses, and optimizing storage and controlled feeding of raw material for subsequent cleaning, drying, and nitration stages [3].

The integrated combination of shredding, decortication, and roll formation significantly reduces labor intensity in the preparation of fibrous raw material for chemical modification. This approach enables the creation of a closed-loop technological cycle of collection and primary processing directly in the field, immediately after flax threshing, thus opening new opportunities for efficient utilization of oilseed flax by-products in the production of energy-dense materials.

The proposed technology is based on a modular principle, which allows the decorticator and roll-former design to be adapted to existing types of harvesting equipment. As a result, the mechanism can be used in both small-scale farming operations and large agro-industrial enterprises. The availability of 3D-printed rollers with various tooth profiles enables quick adaptation of the system to changing raw material properties – from young, tender stems to coarse and overdried ones.

In the future, it is planned to equip the module with a sensor feedback system for monitoring roller load, rotational speed, and material moisture content. This will allow adaptive control of feed rate, roller pressure, and bale formation density, opening up opportunities for digital integration into Smart Farming systems and the broader “smart agropark” concept.

The proposed technology enables the conversion of a by-product (flax straw), which is often burned or left in the field, into valuable raw material. This reduces agroecological pressure, decreases CO<sub>2</sub> emissions, and promotes the establishment of closed-loop biocycles in agriculture. Additionally, residual shive material remaining after nitration may be used as a biofuel source or as filler in composite materials.

The implementation of such a system forms a robust platform for further research in the field of chemical biomass modification, development of new nitrocellulose-based materials (biopolymers, high-energy additives, binding agents), and exploration of shive utilization strategies in the agri-bioindustry.

The proposed technical concept of mechanized extraction of fibrous cellulose fraction from oilseed flax using a roller-type decorticator with interchangeable tooth profiles – combined with in-field use of a roll-former – represents a promising approach to the comprehensive processing of flax straw. This approach effectively addresses several key challenges:

- Utilization of post-harvest flax residues, which still remain a major obstacle to the wider adoption of this crop by agricultural producers;

- Extraction of high-quality cellulose feedstock suitable for nitration to produce nitrocellulose – the primary component of smokeless powder;
- Reduction of dependence on imported technical cotton through the use of locally grown crops adapted to the climatic conditions of Ukraine;
- Formation of a model for the secondary use of agricultural biomass, aligned with the principles of the circular economy and contributing to reduced environmental impact;
- Establishment of an engineering foundation for a scalable technology that can be implemented on an industrial scale using accessible materials and modern digital design tools, including 3D printing and CAD modeling.

Thus, this development creates the prerequisites for the simultaneous revival of the flax industry and the production of energetic materials, particularly nitrocellulose-based propellants, from domestic, renewable, and readily available raw materials – a matter of particular relevance in the context of ongoing armed conflict and increased demand for strategically important substances.

#### **References**

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**МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ**  
**ЖИТОМИРСЬКИЙ АГРОТЕХНІЧНИЙ ФАХОВИЙ КОЛЕДЖ**



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В збірнику представлені тези доповідей науково-педагогічних працівників, наукових співробітників, аспірантів та студентів Житомирського агротехнічного фахового коледжу, провідних вітчизняних і закордонних закладів вищої освіти та наукових установ, в яких розглядаються завершені етапи розробок.

The collection presents abstracts of reports by scientific and pedagogical workers, researchers, postgraduates and students of the Zhytomyr Agrotechnical Professional College, leading domestic and foreign higher educational institutions and scientific institutions, which consider the completed stages of development.

*Передрук або інше відтворення в будь-якій формі в цілому або частково матеріалів, опублікованих у цьому віданні, дозволено лише за посиланням на джерело і дотриманням вимог законодавства*