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## ARTIFICIAL INTELLIGENCE IN THE PROCESSES OF PLANT OIL REFINATION

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### Abstract

Vegetable oils play a key role in the food industry, and their consumer properties directly depend on the level and approach to refining. This article is dedicated to current trends in improving vegetable oil refining technologies, with a focus on applying innovative approaches such as biological methods, advanced technologies, and digitalization through AI and IoT. The combination of intelligent control systems, biotechnologies, and sensory networks leads to improved product quality, optimization of energy and material resources, and creation of a more environmentally friendly production process.

**Keywords:** Refining of vegetable oils, artificial intelligence, IoT, biotechnology, automation, Internet of Things, digitalization, Industry 4.0.

### INTRODUCTION

Vegetable oils occupy an important place in the food and processing industries, serving as a key component for many industries. Their use is widespread in food, medicine, cosmetics, and chemical industries. The sphere of application of vegetable oils goes far beyond the food industry, encompassing pharmaceuticals, cosmetology, feed production, and biotechnology. The refining of vegetable oils plays a key role in ensuring their quality and safety. The effectiveness of the

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applied purification processes allows for the elimination of components such as phospholipids, free fatty acids, pigments, waxes, and substances responsible for odor and toxicity.

Raw vegetable oil is a complex mixture consisting of many components, such as phospholipids, free fatty acids, pigments, metals, oxidation products, and volatile substances. All these components can deteriorate the taste, smell, and appearance of the oil, as well as reduce its resistance and safety for consumption. To get rid of these undesirable impurities, refining is used, which is a multi-stage technological procedure [1-3].

Traditional refining methods, which rely on chemical reagents and high temperatures, guarantee high quality of the final product. However, this approach is accompanied by significant oil loss, depletion of its nutritional value, and the formation of harmful waste for the environment. Given the strengthening of environmental standards and the growing demand for natural products, modernizing refining processes is particularly relevant.

Recent scientific developments indicate that physical refining, enzymatic degumming, and biomechanical approaches to primary oil refining are the most promising for industry development. Increasing production efficiency is also possible through the rational use of refining waste, such as humus and deodorizing distillates.

Progress in digitalization, AI, and IoT opens the way to the emergence of new generations of vegetable oil refining systems that will have adaptability, self-adjustment capability, and environmental orientation.

In this study, a set of modern methods for refining vegetable oils is considered and analyzed, based on advanced scientific developments.

### METHODS

The research was conducted based on a comprehensive analysis of current scientific works devoted to the technology of vegetable oil purification. The work utilized data from generalized and experimental studies covering chemical and

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physical refining, enzymatic degumming, biological methods of primary oil treatment, and the principles of “naturalness” in the food industry.

Oil refining is typically carried out according to a standard scheme consisting of several stages: degumming, neutralization, bleaching, ventilation, and deodorization. Each of these stages is designed to eliminate specific types of impurities from oil and improve its quality for consumers [4-6].

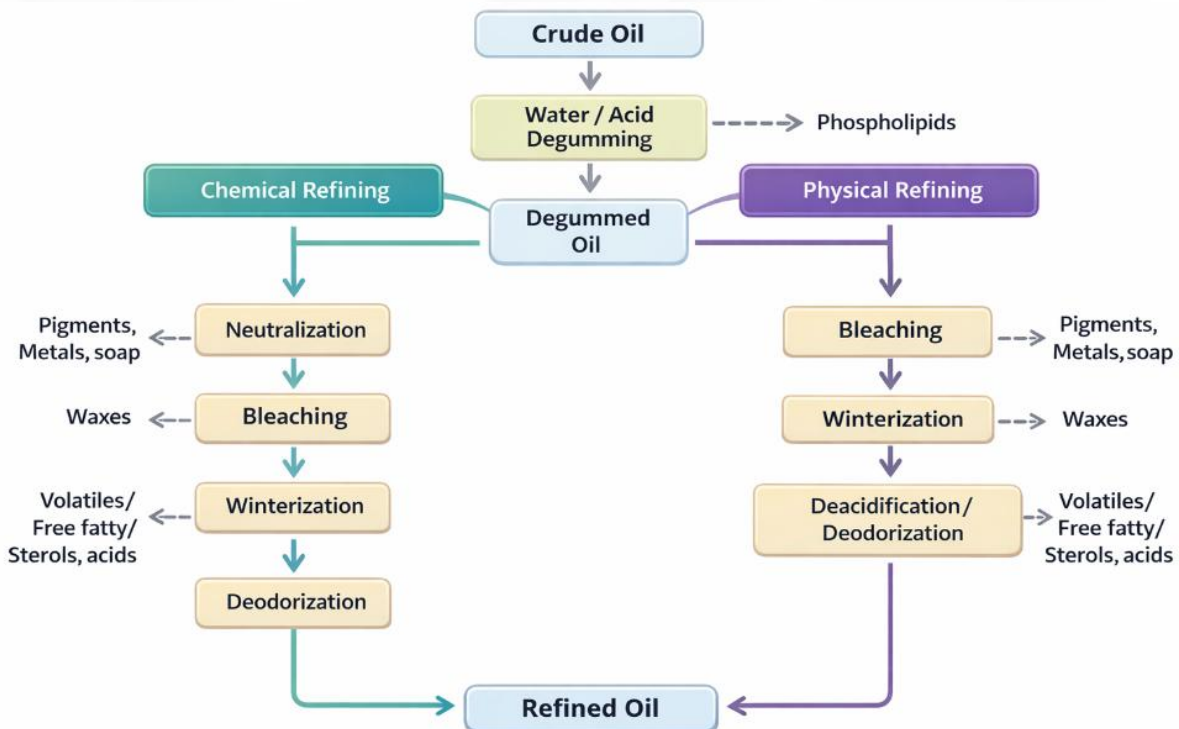


Fig.1. Vegetable oil refining process flow diagram.

Degumming, being the initial stage of the process, is aimed at removing phospholipids from oil. The choice of degumming method (water, acid, or combined) depends on the characteristics of the initial oil. Studies show that chemical degumming is highly effective in reducing phosphorus content, but it inevitably leads to oil loss and humus formation, which has limited value.

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For the elimination of free fatty acids in oil, alkaline neutralization is used. However, this method has its drawbacks: soaps are formed, oil needs to be washed with water, resulting in wastewater.

Bleaching and deodorization processes remove pigments, oxidation byproducts, and volatile components. However, the use of high temperatures in the deodorization process can cause partial destruction of tocopherols and other substances with biological activity.

Unlike chemical refining, the physical method excludes the alkaline neutralization stage. The removal of free fatty acids is carried out by steam distillation during deodorization. Studies have shown that physical refining significantly reduces oil loss and waste volume, which positively impacts its environmental safety compared to chemical refining.

This approach, although promising, has a significant drawback: it requires very high quality degumming and initial materials, which makes it not so universal.

Degumming using enzymes, particularly phospholipases, is an effective method based on the selective breakdown of phospholipids. This approach has several advantages: it allows the process to be carried out under favorable conditions, reduces the need for chemical reagents, and increases the yield of the resulting oil.

The review demonstrates the effectiveness of enzymatic degumming in reducing phosphorus content to values sufficient for physical refining while minimizing the loss of valuable nutrients.

Research in the field of biologically oriented and mechanical cleaning methods at the initial stage revealed significant potential for secondary agricultural processing products. The use of flax fiber, for example, for the initial purification of safflower oil, demonstrates its effectiveness not only in removing mechanical impurities but also in increasing its value by increasing the content of antioxidants and unsaturated fatty acids.

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Fig.2. Main stages of food oil refining.

This approach expands the understanding of primary purification, presenting it not only as a stage of removing impurities but also as a means of enriching the product with biologically active components.

Currently, in the field of oil refining, special attention is paid to developing methods that enhance the selectivity of purification while preserving valuable components. These approaches include:

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- application of щадящих physicochemical methods of refining at reduced temperature regimes;
- use of membrane processes for the separation of phospholipids and unsaturated fatty acids;
- using enzymes such as phospholipase and lipase to carry out biological refining.

Using biological approaches helps reduce the need for chemical reagents, reduce the volume of waste generated, and enhance the environmental safety of production processes.

Artificial intelligence is becoming an increasingly important tool in the refining process. Its implementation allows for the intellectualization of various stages of this complex technological chain. Among the key areas of AI application in refining, we can highlight [7-10]:

- adaptation and improvement of technological parameters (temperature, pressure, and time factors).
- predicting the quality of the final product - oil - using large amounts of information.
- identification of deviations and malfunctions in the process during its implementation;
- control of technical devices using adaptive algorithms based on machine learning.

The use of artificial intelligence algorithms in the process of refining vegetable oils ensures the automatic selection of the best parameters, minimizing dependence on human intervention.

The Internet of Things plays a key role in optimizing refinement processes. Thanks to IoT, production equipment is constantly monitored and data is collected, which allows: control of temperature, pressure, consumption and composition of raw materials; monitoring the operability of the equipment and

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preventing failures; sending information flows to unified processing and control centers.

IoT networks based on sensors form the foundation for the development of “smart” factories, ensuring continuous communication and automated management of each stage of the refining process.

The integration of artificial intelligence (AI) and the Internet of Things (IoT) in intelligent management systems opens up vast opportunities. Using these technologies in tandem yields the most impressive results: IoT collects accurate data, while AI processes it, identifying patterns and allowing for the best decision-making. Thanks to such integration, it is possible to: reduce the use of energy and chemical substances; improve the consistency of the quality of manufactured products; guarantee traceability and openness of the production process; implementation of the Industry 4.0 concept in the oil and fat industry.

### RESULTS

The refining of vegetable oils is traditionally carried out according to a scheme consisting of several key stages: hydration, alkaline neutralization, bleaching, and deodorization. To achieve optimal results at each stage, it is necessary to strictly follow the technological instructions, however, this inevitably leads to significant losses of neutral oil.

Traditional refining faces a number of key challenges. Among them are: the complexity of ensuring precise regulation of technological parameters during the process; a strong dependence on the quality of the initial raw materials, which can change; the destruction of valuable compounds such as tocopherols and sterols; high energy consumption, especially in the deodorization phase.

In this regard, there is an urgent need to develop new, more advanced refining methods. Recent technological developments are aimed at making purification processes more selective and щадящие. These include:

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- application of physical cleaning methods, which leads to a decrease in alkali consumption and minimization of vegetable oil losses;
- application of membrane and adsorption methods to improve the accuracy of purification from impurities;
- to protect heat-sensitive elements, vacuum treatment and low-temperature operation technologies are used;
- the application of these methods leads to an improvement in the quality of manufactured products and optimization of production costs.

Oil refining using biotechnology utilizes enzymes, such as phospholipases and lipases, for the pointwise removal of acid-free components. This method, called enzymatic hydration, ensures the removal of phospholipids with high efficiency while avoiding the use of aggressive chemical substances.

Biological refining has several advantages: it is environmentally friendly, reduces waste, increases the yield of refined oil, and allows for the preservation of valuable biologically active components.

The mass application of biological methods poses the task of precisely regulating technological parameters, which emphasizes the importance of intelligent control systems.

AI serves as a powerful tool for understanding and comprehending the complex structure of technological processes characteristic of vegetable oil refining. The application of machine learning and neural networks opens up wide opportunities for: develop mathematical descriptions of the refining stages; to predict the properties of oil during its processing; improve the parameters of the functioning of equipment; to reveal the implied connections and factors causing deviations.

Thanks to AI, we can abandon fixed operating modes and transition to flexible management that takes into account changes in source materials and the external environment.

The performance of the newly designed system was evaluated through simulations that compared its operation with both a traditional controller and an

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advanced AI-powered control system. The modeling procedure involved an examination of several key metrics, including transient response duration, overshoot, disturbance rejection capabilities, and precision in upholding target parameter values.

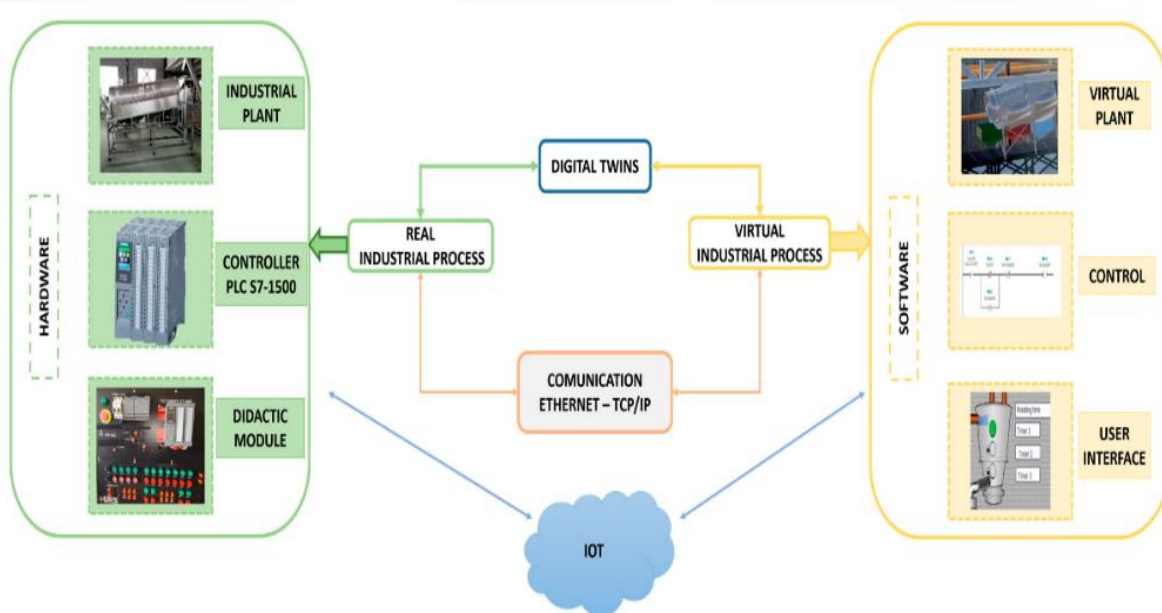


Fig.3. Scheme of the intelligent refining process control system.

This diagram illustrates the structure of an advanced control system, featuring multiple sensor tiers, a programmable logic controller (PLC), an analytical component with enhanced capabilities, and a supervisory control and data acquisition (SCADA) system. Sensor readings pertaining to process variables like flow, temperature, pressure, and concentration are initially received by the PLC, which then forwards this information to the intelligent processing stage. This system involves analyzing data, predicting future process trends, and generating the best possible control strategies. These strategies are subsequently implemented by the designated control systems. Furthermore, the integration of

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a digital twin module enables the performance of virtual tests, isolating them from any impact on the actual process.

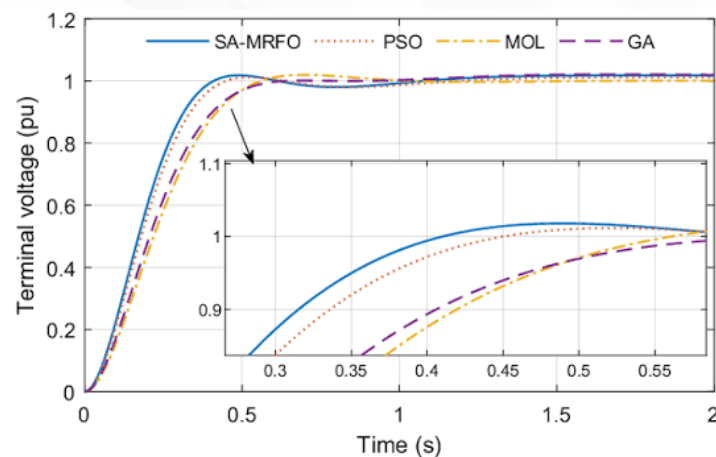


Fig.4. Control characteristics: classic and intelligent approaches.

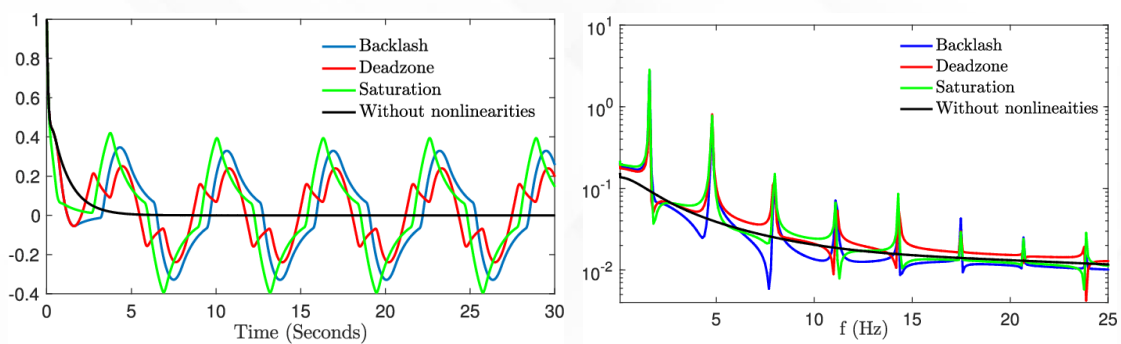


Fig.5. Dynamics of regulation error in various control algorithms.

Simulations revealed that implementing the intelligent control system leads to a 5% to 15% decrease in the time required for processes to stabilize. Additionally, it minimizes over-regulation by 3% to 10%, enhances system stability when faced with sudden load fluctuations, and lowers the typical error rate in maintaining desired control levels.

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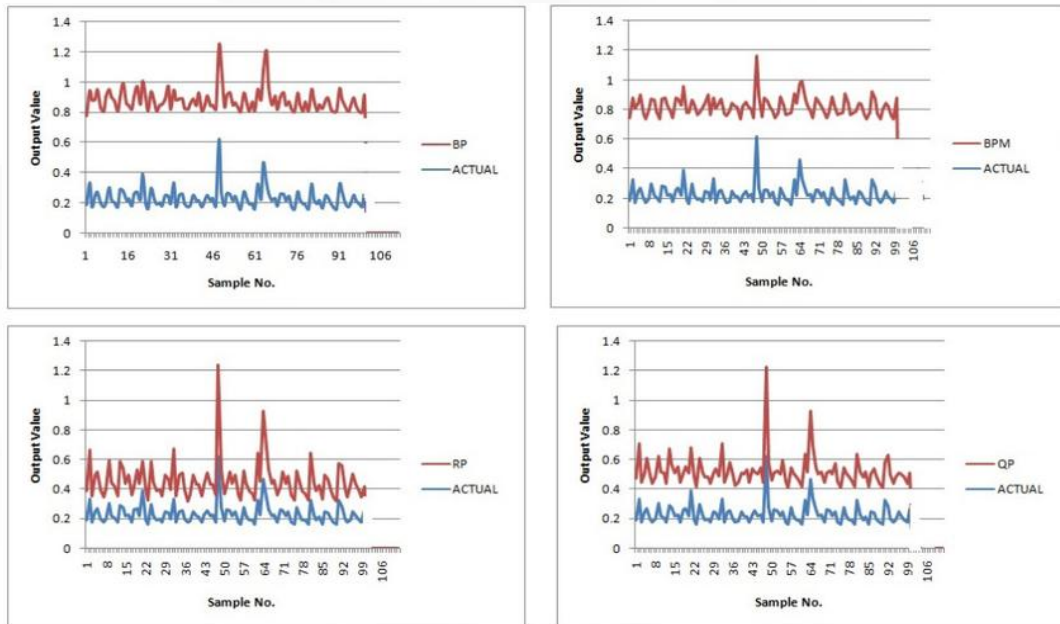


Fig.6. Comparison of actual and forecast values of process parameters.

Neural network forecasting models enable predictions about future shifts in technological specifications, allowing for proactive control measures and a substantial enhancement in operational effectiveness.

### DISCUSSION

The “Internet of Things” system constantly collects information from sensors that measure temperature, pressure, flow rate, acidity, and other characteristics. Thanks to IoT platforms, data from different production points can be combined into a single information resource.

The main tasks of IoT in the field of refining are: monitoring of technical indicators is carried out online; assessment of the equipment's operability; establishing the possibility of tracking and monitoring the progress of processes; transmission of information intended for analysis and management [11-13].

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Intelligent production, where refining processes gain the ability to self-regulate and optimize, is implemented through the tandem of artificial intelligence (AI) and the Internet of Things (IoT). IoT acts as a source of information flow, and AI, processing this data, generates decisions that guide the process.

As a result of such integration, the following advantages are achieved: reduction of energy costs and maintenance costs; stabilization of the quality of manufactured products; reduction of human error; implementation of the Industry 4.0 concept in the oil and fat industry sector.

### CONCLUSION

The use of advanced technologies, including artificial intelligence and IoT, to optimize the processes of refining vegetable oils opens new horizons in the development of the industry. Digitalization of production allows not only to increase its efficiency and reduce environmental footprint, but also to increase competitiveness in the market, while meeting the demands of sustainable development and digital transformation.

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