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# A MINI-REVIEW OF BIODIESEL PRODUCTION METHODS AND ITS PROPERTIES

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Fatty acid esters (FAEs) attract attention worldwide due to their environmental friendliness, renewable nature and the possibility of their use as additives to traditional diesel fuel. Current energy crisis in Ukraine can be solved only under the condition of rational use of all energy sources and search for alternative ones. Among them, the technologies involving FAEs play an important role. The paper discusses various options for the transesterification process of FAEs: non-catalytic and catalytic ones. Information is provided about different types of catalysis. Different raw materials for the production of FAEs of various origins are overviewed. The characteristics of existing installations and methods of the FAE production are given. The main advantages and disadvantages of the above-mentioned aspects of the FAE production are analyzed. Comparison of the physicochemical characteristics of FAEs obtained by different methods is made. Recommendations are given to partially overcome the existing fuel crisis in Ukraine with the help of biofuel production.

**Keywords:** ester, fatty acid, oil, alcohol, catalyst, technology, fuel.

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## *Introduction*

Burning fossil fuels releases a significant amount of carbon dioxide, which traps heat in the atmosphere and contributes to global warming [1]. An alternative to reducing the use of traditional motor fuels and developing ecological and economic processes is the development and research of biofuels [2].

Fatty acid esters (FAEs) contain fewer sulfur compounds and have a higher flash point, emit 80% less hydrocarbons and 50% less toxic particles with exhaust gases [3]; they are distinguished by their renewable, biodegradable, non-toxic and environmental friendliness [4].

According to statistical data, the production of FAEs in Ukraine has not been recorded, although the potential is estimated at 2 million tons per year, since the raw material for production is technical oil, as well as rapeseed and soy, i.e. crops that are actively exported [5].

Fatty acid esters are used in pure form or as an additive to petroleum diesel fuel. General technical requirements for methyl esters of fatty acids and for ethyl esters of fatty acids are regulated by the state standards DSTU 6081:2009 and DSTU 7178:2010, respectively [6].

The quality of FAEs and the technological mode of their production depend, first of all, on the composition and properties of the original oil.

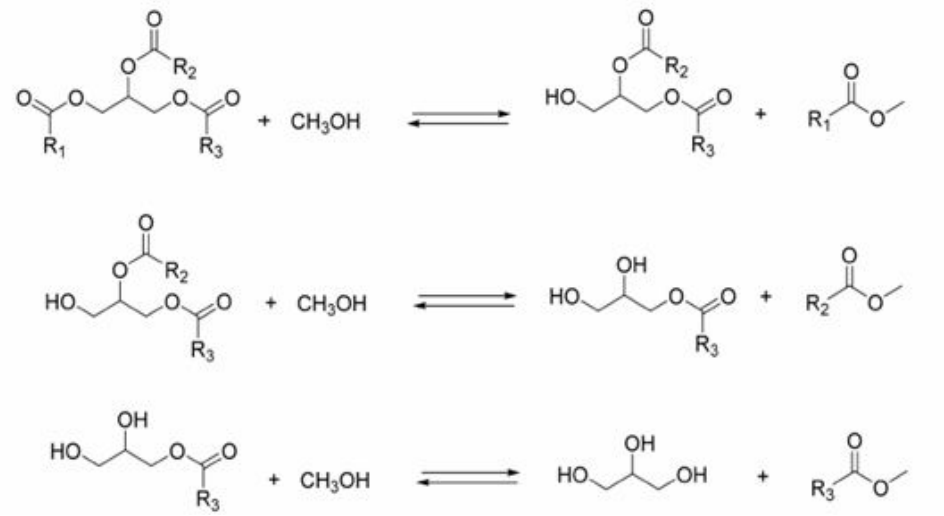
The first generation of FAEs mainly used edible crops. The second generation used technical vegetable oils, animal fats, lard and beef fat. The third generation is algae, which play a very important role in the production of FAEs, possessing numerous advantages such as higher oil content compared to other crops and environmental friendliness. Algae do not affect the environment, requiring a small area for cultivation [3]. Spent oils, industrial and household waste are also used as raw materials [4].

## *Catalytic production of FAEs*

### *Process chemistry*

Traditionally, alternative fuel is obtained by transesterification. The reaction proceeds in the presence of alkaline or acid catalysts. The process consists of three consecutive and reversible reactions in which triglycerides are converted to diglycerides, then to monoglycerides and finally to glycerol.

Fatty acid esters are formed in each of the three reactions. Thus, starting from a triglyceride molecule, at the end of the overall reaction, three molecules of esters are produced, and glycerol is formed as a byproduct (Figure) [3].



General reaction scheme of transesterification in the presence of methanol

Methanol is usually used due to its economic feasibility. FAEs production is affected by various factors, such as temperature, reaction time, catalyst concentration, and the molar ratio of alcohol to oil. As a rule, the reaction rate increases with increasing the temperature. Due to the nature of the catalyst, its concentration significantly affects the technological process. A large catalytic surface area reacts faster and the reaction will be completed in a short time, while a large catalyst concentration slows down the reaction [7].

The processes of transesterification are divided into the following groups:

1. Catalytic process

1.1. Homogeneous catalysts.

1.1.1. Alkaline: KOH, NaOH, $NaOCH_3$, $KOCH_3$, and $K_2CO_3$.

1.2. Heterogeneous catalysts

1.2.1 Enzymes: immobilized lipase, and $CH_2N_2$.

1.2.2 Titanium silicates, sulfated titanium, alkaline earth metal oxides (MgO, CaO, SrO), and amorphous zirconium dioxide.

2. Non-catalytic process.

2.1. Supercritical alcohols.

2.2. BIOX co-solvent process.

*Homogeneous alkaline catalyst*

A homogeneous alkaline catalyst is most commonly used in FAE production due to its ability to react at low temperatures and atmospheric pressure, providing high conversion in a short time [3]. NaOH, $CH_3OH$ and KOH are most often used [8]. When using alkali, the following side reactions occur concurrently with the main reaction: neutralization of free fatty acids, saponification of mono-, di-, triglycerides of higher fatty acids and FAEs.

This type of catalyst is advisable to use when the content of free fatty acids (FFA) and moisture is no more than 3% and 0.05%, respectively. Otherwise, the reaction with FFA leads to saponification, deactivation of the catalyst and a decrease in the conversion yield of the target product [2]. The number of saponification products increases with an increase in catalyst concentration over 1.3%, the duration of the process, and an increase in temperature up to $50^0$C [6].

The main disadvantages of the catalyst include foaming and difficulty in extraction, which leads to an increase in the production costs of FAEs [9].

*Homogeneous acid catalyst*

The results of homogeneous acid catalysis are not influenced by the presence of FFA, which allows using cheap raw materials. The efficiency of catalysts is higher when the FFA content is more than 1%. However, the process has disadvantages, including a lower reaction rate, high temperature and alcohol/raw material molar ratio, difficulties in catalyst separation, and environmental issues [3].

*Heterogeneous alkaline catalyst*

The main disadvantages of homogeneous catalysts are resolved by using heterogeneous catalysts [8]. The system consists of a solid homogeneous catalyst and two liquid phases that are mixed. Synthetic catalysts based on hydroxides of alkali metals (Na, and K) and oxides of alkaline earth metals (Ca, Mg, Sn, and Zn) were studied. Heterogeneous solid catalysts are easily recovered and reusable, and they do not require a separation step, but are less efficient than homogeneous catalysts.

*Heterogeneous acid catalyst*

The use of solid acid catalysts such as zeolites,

ion exchange resins, sulfated metal oxides, and sulfated carbon fibers has several advantages. The catalyst is more easily separated from the reaction medium, regenerated, and processed. However, the heterogeneous acid catalyst is less active, requires a longer reaction time, high temperature, pressure, as well as a higher molar ratio of alcohol/oil compared to alkaline catalysts [3].

*Bio-based catalysts*

Research into the effectiveness of a calcium-potassium (Ca–K) catalyst on a bio-based basis is being conducted. This catalyst can be regenerated. The bio-based catalyst maintained its catalytic activity from the 1st cycle to the 4th cycle with a slight decrease from 93.6 wt.% to 92.20 wt.%. However, in the 5th and 6th cycles, a significant decrease (89.7 and 88.7 wt.%) was observed, due to the glyceride groups that blocked the catalyst holes. Regeneration of this catalyst can be carried out without a significant loss of efficiency no more than 4 times [7].

*Enzymes*

The use of enzymes as biocatalysts in the production of FAE allows reducing the cost of production. Enzymes have numerous advantages such as biodegradability, reusability, simultaneous conversion of FFA and triglycerides to FAEs, no by-products, mild operating conditions and easier product separation. In addition, they prevent the occurrence of side reactions, such as saponification and hydrolysis. However, enzymes have disadvantages such as high cost, longer reaction time, inhibition by methanol, and limited self-regeneration [3].

*Non-catalytic FAEs production*

In the non-catalytic process of transesterification, no catalyst is used, therefore no saponification occurs, and there is no need to remove the catalyst. Two methods are mostly used: the process under supercritical conditions and the process with BIOX co-solvent [8].

Under supercritical conditions, the mixture becomes a single homogeneous phase that accelerates the reaction, since there is no mass exchange phase that limits the reaction rate. Alcohol is both a reagent and a catalyst. It is advisable to add water to improve product separation, which increases the FAE yield. The main disadvantages of this process are the high cost of the equipment due to the high temperature (170–350$^0$C) and pressure (10–60 MPa) [3].

Glycerol implies problems in classical catalytic transesterification, as further steps are required to separate the glycerol fraction and FAE. Under supercritical conditions, glycerol thermally decomposes and reacts with alcohol, forming glycerol esters, diglycerols and alcohols, which are mixed with FAE, through esterification reactions. The presence of these low-molecular-weight compounds can improve the cold flow properties and viscosity [10]. In addition to methanol and methyl acetate, ethanol, methyl tert-butyl ether and dimethyl carbonate are also used.

Methyl tert-butyl ether and tetrahydrofuran are used as inert BIOX co-solvents to create a single-phase system by dissolving alcohol in it. This process allows reducing the reaction time (up to 5–10 minutes), as it increases the solubility of alcohol in the co-solvent [8].

***Raw materials***

*Edible and non-edible fatty raw materials*

The main producers of FAEs worldwide are the European Union (rapeseed, and soybean), the United States (soybean), Brazil (soybean), Indonesia and Malaysia (palm oil) and China (rapeseed), which are used as feedstock for edible vegetable oil [8]. The use of technical sunflower oil, chicken, fish, pork and beef fats is relevant for Ukraine.

The choice of raw materials depends on their availability and volumes, for example, the volume for oils depends on productivity per hectare. In addition, the content of free fatty acids and moisture should be taken into account in the raw materials.

*Oil from micro-algae*

Microalgae are the most efficient biological producer of natural hydrocarbons in the form of fatty acids, and therefore a universal renewable source of biomass suitable for rapid processing into fatty acid esters.

Currently, a huge number of methods of cultivating phototrophic microorganisms are used, but not all of them can ensure a low cost of finished products [11].

In order to reduce the cost of production, the development of the technology of cultivation of microalgae strains on thermal and mineral springs is relevant. Selection of strains and their characteristics make it possible to use water resources of different quality for cultivation of strains with desired phenotypes and characteristics.

The composition of lipids in cells largely depends on the type and conditions of cultivation of microalgae. Microorganisms can change the biochemical composition of cells (carbohydrates, proteins, and lipids), reacting to the change in the concentration of biogenic elements in the nutrient medium. Nitrogen affects the cellular structure of microalgae, as it is necessary for the synthesis of proteins, amino acids, nucleic acids, enzymes, and photosynthetic pigments [12].

Lack of nitrogenous substances stimulates the

accumulation of intracellular neutral lipids, triacylglycerides. The amount of lipids increases by 1.7–15 times. With a lack of nitrogen and an excess of carbon in the nutrient medium, microalgae can accumulate up to 88% of oil [11].

Due to unfavorable climatic conditions and geographical location, growing microalgae biomass in open sources is not a promising direction for Ukraine. The use of bioreactors makes it possible to use industrial waste as a medium and obtain a high yield of biomass during cultivation.

The work [13] presents a SWOT analysis matrix of the FAE production from microalgae oil in Ukraine.

The advantages of production include the following: the possibility of growing biomass in open/closed systems, the speed of growth of biomass, a wide range of biofuels, ecological properties, reduction of greenhouse gas emissions, and no need for suitable arable land.

The weaknesses include the following: dependence on climatic conditions, high viscosity of algae oil, significant initial capital investment, the lack of strains for large-scale cultivation, and the lack of a unified research program in this field.

The production of FAEs from microalgae will allow reducing dependence on traditional motor fuels, and rationally using the waste of sugar and pulp production as a nutrient medium for technological processes of microalgae cultivation. Nevertheless, this technology is not competitive in relation to traditional types of fuels due to the low profitability of production [13].

***Production methods***

For the production of FAEs, several types of units and reactors are used, each of which allows different operating conditions regarding the chemical nature of reagents and products, as well as operating parameters.

*Unit of continuous operation*

In a continuous process, transesterification is carried out in two consecutive reaction circuits with intermediate selection of the formed glycerin, which allows increasing the product yield. The initial components are volumetrically dosed by a pump into the reaction circuit of the first reactor, in which optimal temperature and pressure are ensured. The reaction is carried out at a temperature of 90–110$^0$C and a corresponding pressure of 0.3–0.4 MPa. The first reactor has a static separator, from which a layer of FAE and unconverted triglycerides enters the reaction circuit of the second reactor, where it is mixed with fresh alcohol and a catalyst. The reaction products from the bottom of the reactor pass through a centrifuge in which glycerol is separated, and the fat flow returns to the reaction circuit of the first reactor.

FAEs are fed into the vacuum tank of the methanol selection unit, where they are heated and undergo deep vacuum cleaning. Alcohol vapors are condensed in the heat exchanger. After the alcohol selection unit, FAEs enter the residual alcohol purification unit using ion exchange resins and the mechanical impurities filtration unit [14].

This method provides a high yield of FAEs, continuity of the process and a high reaction rate. However, the complexity of the technological process and sufficiently high sensitivity to the quality of raw materials limit the scope of application [15].

*Unit of periodic action*

In a batch process, raw materials, catalyst and alcohol are preloaded into the reactor, where they are heated to a temperature of 70$^0$C. The resulting mixture is settled and glycerol is separated. The yield of FAEs is 97%. The obtained esters are processed in different ways depending on their further application.

The unit consists of two main groups of modular units. The first group of modular units of reactors is required for the chemical and technological process. The second one consists of storage tanks for raw materials, finished products and by-products.

The first group of modular blocks consists of the following:

– reactor No. 1, where proceeds the process of absorption, purification of raw materials and bringing them to the required parameters;

– reactor No. 2, in which proceeds the main reaction;

– reactor No. 3, in which potassium hydroxide is dissolved in alcohol.

– reactor No. 4, designed for washing FAE from alcohol and glycerin residues.

Prepared oil (fat) from reactor No. 1 is heated to 60$^0$C and compounded for 15 minutes with a mixture of alcohol and catalyst from reactor No. 3. At the end of the process, the mixture is separated into glycerol and FAE, which are then sent to washing reactor No. 4 [16]. This unit is distinguished by the relative simplicity of the technological process, the low cost of the technological line and the possibility of using low-quality raw materials. The disadvantages include the following: a low yield of FAEs and a long duration of the reaction [15].

Differences in technological schemes of the FAME production process by transesterification of vegetable oil with methanol are as follows:

– in the continuous process, pre-purified oil

(fat) is used, in the periodic process, the raw material is cleaned of impurities and brought to the required parameters in reactor No. 1;

– in the continuous process, oil (fat), catalyst, and alcohol are fed into the reactor separately, in the batch process, the dissolution of the catalyst in alcohol takes place in a separate reactor. Prepared raw materials and a pre-prepared mixture of alcohol and catalyst are fed into the main reactor;

– mixing in a continuous process is performed using a hydrodynamic mixer without additional heating of the mixture in the reactor, and in a batch process - using a jet pump with constant heating of the mixture in the transesterification reactor;

– in a continuous process, crude fatty acid esters undergo vacuum drying and are passed through a layer of ion-exchange resin (to separate alcohol), and in a batch process, crude FAE in reactor No. 4 are washed by irrigation with circulating water [16].

*Cavitation unit*

The operation of cavitation reactors is based on the effect of cavitation (the formation of gas-filled cavities in the liquid), which occurs as a result of a local decrease in pressure in the liquid, which can occur either with an increase in its speed (hydrodynamic cavitation) or with the passage of an acoustic wave of high intensity. Moving along with the flow to a zone with higher pressure, the cavitation bubble bursts, causing the appearance of a shock wave.

Cavitation is divided into four main types, according to the method of creating cavities: acoustic, hydrodynamic, optical and magnetic pulse. Acoustic cavitation uses ultrasound to create cavities. Hydrodynamic cavitation is a phenomenon in which a large number of cavities are formed due to the pressure drop of a liquid passing through a constriction. Optical cavitation is based on pressure change. Magnetic pulse cavitation differs from the usual cavitation process by the effect of the magnetic field on microplasma formations that occur during active cavitation [17].

Among the four types of cavitation, only acoustic and hydrodynamic cavitation produce sufficient intensity required for the FAEs production.

The advantage of cavitation reactors is their high productivity. However, this may reduce the quality of FAEs, since the very short time during which the reagents are mixed does not always ensure the formation of a high-quality target product.

*Membrane reactor-assisted unit*

Membrane technologies are able to separate different elements in a single technological unit. The membrane reactor ensures the passage of only components with a smaller molecular size, retaining components with a large molecular size. This method strengthens the interaction between the oil and the catalyst, which allows you to get the maximum yield of the product.

Alcohol and oil are alternately added to the mixing tank with a promoter based on CaO and activated carbon, and then methanol is continuously introduced. This reactor allows synthesizing FAEs without additional purification and washing. The maximum ester conversion of 96.9% was achieved at 65$^0$C for 90 min, alcohol:oil molar ratio of 4.2:1 and catalyst concentration of 3.0 wt.% [9].

This method has significant advantages compared to traditional ones. When using membrane technology, a small amount of wastewater is generated. In addition, the membrane can be used as a means of treating wastewater generated during FAE separation and purification [18].

*Microwaves-assisted unit*

FAEs can be obtained using microwaves with a frequency between radio and infrared waves, which accelerate the chemical reaction between alcohol and raw materials, reducing the reaction time from hours to minutes. For the transesterification process, the moisture content and free fatty acids must be very low; otherwise, the alkaline-type catalyst will be spent on their neutralization, and the moisture will form soap and foam, which will make it difficult to separate the glycerin fraction. It is necessary to determine the optimal values and the number of different variables to obtain the maximum yield of FAEs from different raw materials [8].

In work [19], a continuous flow microwave reactor was used for the transesterification of palm oil with methanol; a FAME yield of 99.4% was achieved at 400 W for 1.75 min.

***Purification of the target product***

Separation of FAEs from catalysts, excess alcohol, glycerin and unreacted oil residues is essential to ensure the required quality and engine protection. The choice of cleaning methods depends on the catalyst used.

In the presence of alkali, the following side processes occur along with the main reaction: neutralization of free fatty acids, and saponification of mono-, di-, triglycerides of higher fatty acids and FAEs [6]. The number of saponification products increases with an increase in the concentration of the catalyst over 1.3%, the duration of the process, and an increase in temperature up to 50$^0$C.

When using a homogeneous alkaline catalyst, washing with water is used [20]. This stage involves washing first with acidified water, and then with neutral water to remove impurities dissolved in water,

alcohol and glycerin residues. However, this method is unsuitable for washing FAE produced using heterogeneous catalysts, as it leads to the formation of calcium soap.

The precipitation method is used to remove calcium ions (heterogeneous reactions catalyzed by CaO) using various precipitants such as oxalic and citric acids, and the resulting precipitate can be easily removed by precipitation.

FAEs produced using enzymes and heterogeneous bio-based catalysts are removed by centrifugation.

There are two main methods of vacuum drying. According to the first method, FAE(1) is separated from the glycerol fraction, washed with a weak organic acid solution, then with water and dried under vacuum. According to the second method, FAE(2) is isolated from the reaction mixture without prior preparation by vacuum distillation at a pressure of 100−130 Pa and a temperature of 170−220$^0$C. This method makes it possible to obtain a product of maximum purity, but with a lower yield, which decreases in proportion to the yield of the cubic residue. Vacuum distillation allows obtaining 99.8% of methanol [21]. The recovered methanol and heterogeneous catalysts can be recycled back into the process. Crude glycerin can be used as a raw material for other chemical processes, but it contains a high amount of impurities (soap, alcohol, glycerides, etc.) that prevent its direct use. To solve this problem, methods of neutralization, microfiltration, and exchangeable resins are used to process raw glycerin.

The reduced density and viscosity of FAE(2), purified by vacuum distillation, is caused by the increased content of esters with a shorter length of the hydrocarbon radical. FAEs(2) are distinguished by a higher flash point and lower moisture content, which is due to the distillation of volatile components at high temperatures, as well as lower acid numbers, since free fatty acids mainly remain in the cubic residue.

The main differences in the characteristics of FAE(1) and FAE(2) are the high content of esters

**Test results on batch process, continuous process and cavitation reactor units**

| Parameter | Value according to the state standard DSTU 6081:2009 | The test results are actually received | | |
|---|---|---|---|---|
| | | Unit of periodic action | Unit of continuous operation | Cavitation unit |
| Mass fraction of esters, %, not less than | 96.5 | 96.5 | 98 | 96 |
| Density at a temperature of 15$^0$C, kg/m$^3$, within | 860–900 | 879.7 | 881.2 | 883 |
| Kinematic viscosity at a temperature of 40$^0$C, mm$^2$/s, within | 3.5–5.0 | 4.94 | 4.97 | 3.74 |
| Flash point in a closed crucible, $^0$C, not less than | 120 | 170 | 164 | 48 |
| Mass fraction of sulfur mg/kg, not more than | 10 | absence | absence | absence |
| Coking, %, not more than | 0.30 | 0.08 | 0.08 | 0.20 |
| Ash content, % by weight, no more than | 0.02 | 0.001 | 0.001 | 0.01 |
| Mass fraction of water: %, not more than | 0.05 | 0.03 | 0.04 | 0.06 |
| The content of mechanical impurities: mg/kg, not more than | 24 | | | |
| %, not more than | absence | absence | absence | absence |
| Copper strip corrosion rating (3 hours at a temperature of 50$^0$C) | withstand the test. Class 1 | withstand the test | withstand the test | withstand the test |
| Acid number, mg KOH per g, not more than | 0.50 | 0.50 | 0.50 | 1.07 |
| Iodine number, g of iodine per 100 g, not more than | 120 | 56.4 | 55.6 | 31.2 |
| Mass fraction of methanol, %, not more than | 0.20 | 0.1 | 0.1 | 1.0 |
| Mass fraction of monoglycerides, %, not more than | 0.80 | 0.6 | 0.78 | 0.8 |
| Mass fraction of diglycerides, %, not more than | 0.20 | 0.17 | 0.19 | 0.32 |
| Mass fraction of triglycerides, %, not more than | 0.20 | 0.20 | 0.18 | 0.2 |
| Mass fraction of free glycerol, %, not more than | 0.02 | 0.02 | 0.018 | 0.02 |
| Mass fraction of alkali metals: (Na+K), mg/kg, not more than | 5.0 | 3 | 4 | 10 |
| (Ca+Mg), mg/kg, not more than | 5.0 | | | |
| Mass fraction of phosphorus mg/kg, not more than | 10 | 8 | 8 | 9 |

in FAE(2), as well as low resistance to oxidation. Oxidation resistance is due to the presence of fat-soluble antioxidant vitamins (tocopherols), the amount of which decreases during refining. Depending on the refining method, the concentration of tocopherols in vegetable oils decreases by 25–70%, which leads to a decrease in resistance to oxidation.

Up to 14% of tocopherols and half of sterols go into the glycerol fraction. During vacuum distillation, natural antioxidants remain in the cubic residue, so FAE(2) does not contain them. The content of tocopherols in FAE(1) is quite high, which provides the necessary resistance to oxidation. Thus, the resistance to the FAEs oxidation depends significantly on the method of their purification [6].

***Physicochemical properties of various FAEs***

Comparison of the physicochemical parameters of FAEs obtained using various technological processes was carried out. The results of the FAE tests, obtained in batch and continuous units, as well as in a cavitation reactor, are shown in Table. All test results given are averages for two different continuous-action units, four batch-type units and four cavitation units.

The necessary viscosity and density of the fuel ensure normal fuel supply and atomization in the combustion chamber. The obtained results are within the limits allowed by the standards.

The flash point in a closed crucible on batch and continuous units is more than 170$^0$C, so this fuel is more fire-explosive. The low flash temperature of FAEs, 48$^0$C, obtained on the cavitation unit can lead to engine problems [22].

Methyl esters of fatty acids do not contain sulfur, as they are made from vegetable raw materials.

Coking does not exceed the norms according to the Ukrainian state standards (DSTU), therefore, when burning in the engine, the fuel will not form deposits on the parts.

The mass fraction of water in the samples obtained at intermittent and continuous units does not exceed the norm, but it is more than the permissible norm at cavitation units. This indicates the quality of product separation.

The test on a copper plate characterizes the presence of sulfur and the ability of fuels not to cause corrosion of the engine fuel system parts made of copper-containing alloys. This parameter meets the requirement.

The mass fractions of monoglycerides, diglycerides, triglycerides, free glycerol and methanol, the acid number in the fuel, obtained at intermittent and continuous units, meet the norms according to the DSTU.

In the samples obtained at the unit using the cavitation process, the above-mentioned parameters do not meet the standards. The mass fraction of alkali metals (Na+K) also exceeds the norm, which indicates that the catalyst is not completely separated during the production process.

Modern units of periodic operation allow obtaining FAEs of sufficiently high quality. An important factor is high-quality and complete settling and purification of the obtained fatty acid esters. This is also characteristic of the continuous production process.

Cavitation units usually produce fuel with a low flash point, high methanol content, and alkali metal content. We believe that these units will require a FAE separation and purification unit to remove unreacted source components taking into account the specifics of the cavitation process.

***Conclusions***

Currently, biofuel is considered in Ukraine as a significant alternative to traditional energy resources. We have considered raw materials, catalysts and methods of production of fatty acid esters. The use of non-edible and waste oils and fats as raw materials is promising. Fatty acid esters produced from microalgae oil provide a more sustainable and environmentally friendly alternative to fossil fuels, but such production is currently not economically feasible. Heterogeneous catalysts are more commonly used due to the ease of their recovery and reuse compared to homogeneous catalysts. In addition, they are more environmentally friendly and can work on units in a continuous mode.

Various production methods can provide high yields of the target product in a short reaction time and at a lower alcohol/oil ratio. All production methods considered in this paper showed a yield of fatty acid esters of more than 95%. The physicochemical parameters of FAEs obtained at intermittent and continuous units meet the requirements of the standards. The quality of FAEs samples obtained at cavitation units can be improved by using the process of separation and purification from alcohol, catalyst and glycerin residues.

The economy of the production process can be improved by integrating the production process with the recovery process and converting the by-products into other valuable products.

In the conditions of the fuel crisis, in order to ensure the energy independence of the state, it is advisable to reduce the export of oil crops, use of non-edible fats for the production of motor fuel components.

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## МІНІ-ОГЛЯД МЕТОДІВ ОДЕРЖАННЯ БІОДИЗЕЛЯ ТА ЙОГО ВЛАСТИВОСТІ

***О.Б. Шевченко, Д.В. Попитайленко***

Естери жирних кислот (ЕЖК) привертають увагу в усьому світі завдяки екологічності, відновлюваності й можливості їх застосування як добавки до традиційного дизельного палива. Поточна енергетична криза в Україні може бути вирішена тільки за умови раціонального використання всіх джерел енергії та пошуку альтернативних. Серед них важливу роль мають відігравати технології з використанням ЕЖК. У статті розглянуто різні варіанти процесу переетерифікації ЕЖК: некаталітичний та каталітичний, наведено інформацію про різні види каталізу. Проведений огляд сировини виробництва ЕЖК різного походження, наведена характеристика існуючих установок та методів виробництва ЕЖК. Проаналізовано основні переваги й недоліки вищевказаних аспектів виробництва ЕЖК. Здійснено порівняння фізико-хімічних характеристик ЕЖК, одержаних різними методами. Надано рекомендації до часткового подолання наявної паливної кризи

в Україні за допомогою виробництва біопалива.

**Ключові слова**: естер, жирна кислота, олива, спирт, каталізатор, технологія, паливо.

## A MINI-REVIEW OF BIODIESEL PRODUCTION METHODS AND ITS PROPERTIES

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Fatty acid esters (FAEs) attract attention worldwide due to their environmental friendliness, renewable nature and the possibility of their use as additives to traditional diesel fuel. Current energy crisis in Ukraine can be solved only under the condition of rational use of all energy sources and search for alternative ones. Among them, the technologies involving FAEs play an important role. The paper discusses various options for the transesterification process of FAEs: non-catalytic and catalytic ones. Information is provided about different types of catalysis. Different raw materials for the production of FAEs of various origins are overviewed. The characteristics of existing installations and methods of the FAE production are given. The main advantages and disadvantages of the above-mentioned aspects of the FAE production are analyzed. Comparison of the physicochemical characteristics of FAEs obtained by different methods is made. Recommendations are given to partially overcome the existing fuel crisis in Ukraine with the help of biofuel production.

**Keywords:** ester; fatty acid; oil; alcohol; catalyst; technology; fuel.

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