Production of biodiesel from low-quality vegetable oils with a high content of free fatty acids by alkaline transesterification

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Abstract. The extraction of natural fats as well as the production of derived products based on them are renewable processes that play a major role in the modern energy industry. An example in this regard is the so-called biodiesel fuel which is Fatty Acid Methyl Esters (FAME), the production of which in recent years has reached enormous scales. Its main advantage is that it is an ecological product (methyl ester of higher fatty acids), which before and after use does not pollute the environment. Quality biodiesel fuel, in turn, is obtained from quality raw materials, which invariably limits its production. On the other hand, every year as a result of improper storage or processing, as well as obtained as waste products huge amounts of low-quality oils remain unutilized and they in turn, represent a valuable raw material and source of energy after their conversion into biodiesel fuel. The present work investigates the possibility of obtaining methyl esters of fatty acids (biodiesel) from low-quality (bad-quality) vegetable oils with high acid values by transesterification with an alkaline catalyst, which includes the selection of suitable catalysts and conditions for the optimal course of the process.

1 Introduction

Although vegetable and animal fats are an important natural source of energy in nature, they are also consumed by other branches of industry such as the food, chemical, cosmetic and pharmaceutical industries, in the household, etc., which reduces the possibilities of their use for energy purposes. The energy obtained during their burning is comparable to that during the burning of oil products, due to their close physico-chemical parameters. Unfortunately, nowadays, the possibilities of obtaining biodegradable products as renewable energy sources are limited, on the one hand. On the other hand, their increased consumption leads to an inevitable increase in their prices, which is unacceptable from the point of view of their competitiveness with mineral raw materials. For this reason, renewable energy sources are currently mostly used in areas with increased environmental risk, for example in urban transport, agriculture, parks, greenhouses, etc.

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At the beginning of the 1970s, in search of a renewable alternative to conventional fuels, the attention was directed to vegetable oils. But the direct replacement of mineral diesel fuel with vegetable oil would be possible only if the operating characteristics of vegetable oil are close to those of diesel fuel or after structural changes to conventional diesel engines.

This makes the direct use of vegetable and animal fats as diesel engine fuel largely impractical due to the following reasons:

- **high viscosity of vegetable oils and animal fats**, which affects the operation of the fuel pump and the geometry of the fuel torch, and hence the efficiency of fuel combustion and the degree of deposit formation;

- **low volatility**, affecting the rate of formation of the fuel-air mixture, and hence the completeness of fuel combustion;

- **poor low-temperature properties** - vegetable and animal fats have a high clouding and solidification temperature (clouding and solidification point), which makes them difficult to use in winter conditions;

- **oxidation instability**, which in turn creates storage problems, as well as possibilities for polymerization and varnish deposits when operating at high temperatures.

In addition, vegetable oils and animal fats have a number of advantages, such as:

- **excellent lubricity** – these are natural lubricants in nature;

- **high calorific value** - their burning is associated with a large amount of released thermal energy;

- **biodegradability** – in case of leakage from the fuel system and spills, it does not pollute the environment;

- **renewability** – practically an inexhaustible resource, as it is a product of plant or animal origin.

These qualities provoke researchers and designers to still look for ways to implement vegetable oils in internal combustion engines. In many cases, compromise options are applied that partially solve the problems with alternative fuels based on vegetable oils.

The main component of vegetable oils is esters of higher fatty acids (HFA) with the trivalent alcohol glycerol (triacylglycerols). The replacement of glycerol with monovalent alcohol leads to a reduction of the molecular mass, and from there to a change in the physico-chemical and performance indicators of the oils.

HFA esters with lower alkyl alcohols (methanol, ethanol, propanol, etc.) make it possible to achieve exploitation indicators characteristics close to those of mineral diesel fuel, by **reducing viscosity, improving evaporation, low-temperature properties** and **oxidative stability**, and at the same time preserving the advantages of vegetable oils in terms of: **environmental friendliness (biodegradability), lubricating qualities, renewability** and **calorific value**.

Practice shows that it is the transesterification of vegetable oils with lower alcohols, mainly methyl alcohol, that allows to obtain the so-called biodiesel fuel (BDF) with properties close to those of mineral diesel fuel, which is why it is possible to use it directly in diesel internal combustion engines without fundamental redesigns of modern engines are required.

The main raw materials used for BDF are vegetable oils: rapeseed, soybean, cottonseed, palm and sunflower oil. An additional source of raw materials is also oils with deteriorated performance. It is known that high quality vegetable oils obtained after appropriate refining are used for food and industrial purposes. The wasteful products after using the oils in various areas are thrown away or used as animal feed. The same is observed when the quality of raw materials deteriorates due to improper storage or processing. In the interest

of maximum and efficient utilization of vegetable oils, these waste products could also be used as diesel engine fuels after appropriate processing. In addition, the use of low-quality raw materials significantly reduces the cost of the final product, which is a sought-after effect in the production of alternative fuel for diesel engines.

2. Analysis of the situation

The application of agricultural machinery and the consumption of significant amounts of diesel fuel is necessary when it comes to the development of agriculture and the production of agricultural products. Therefore, agriculture depends on the extraction of oil and the production of petroleum products. There is an increasing trend in the consumption of fossil fuels, as well as their depletion, which leads to an increase in the price of fuels, and hence the price of agricultural production.

Furthermore, the use of mineral fuels is considered to cause environmental pollution and is an ecological risk, as it creates emissions of harmful gases, and because of the low biodegradability of mineral fuels.

A number of studies show the possibility of completely replacing diesel fuel with biodiesel, or of the usage of different ratios of diesel/biodiesel mixtures (B5, B10, B20, B50, etc.) [1]. The standard EN 14 214 regulates the quality requirements of biodiesel fuels.

Previously, agriculture was not dependent on external resources; such achievement for the modern agriculture could influence the current world economy in a positive way in different ways. First, because of the price of agricultural production, and second, because of the diversion of fossil resources to other productive sectors.

The obtaining of alternative diesel fuels, based on other raw materials, such as vegetable oils, would reduce the agricultureal sector's dependency. Yet this requires the solving of different essential problems, in terms of production as well as consumption of alternative fuels:

- Ensuring their compatibility with the contemporary diesel engines;
- Identification of suitable oil crops that could be used in the production of such fuels, as well as selection of opportunities for using a wide range of raw materials;
- Making sure the necessary quantities of vegetable oils are available in the production and provision process;
- Ensuring effective production capacities of vegetable oils and technologies, used in the production process of fuels;
- Preservation of the operational qualities of the fuel during storage for different periods of time.

On the other hand, vegetable oils are a raw material for the food industry, as well as the main raw material for the production of paints and varnishes. This limits the use of vegetable oils as fuels for multiton productions requiring large quantities of resources of constant quality.

Providing a large assortment of raw materials is an easier task for smaller producers due to the greater "flexibility" in terms of raw materials and the possibilities for their rapid replacement, even for relatively small quantities of starting raw materials.

In the low-tonnage production of ME suitable for application as biodiesel fuel, raw materials of degraded quality can also be used, such as oils with an increased content of free fatty acids. These are oils that have been left for a long time, where the level of free fatty acids has increased as a result of hydrolytic processes, as well as waste frying oils, where the physicochemical properties of the oils vary widely.

Current research shows that it is possible to obtain biodiesel fuel by an alkaline transesterification method even with raw materials with an increased content of free fatty

acids without the need for pre-processing of the oils. This makes it possible to use a wider range of raw materials with a simplified technological scheme of the process and relatively cheap equipment.

A review of the literature data shows a large selection of raw materials for obtaining ME [2]. However, the selection of suitable vegetable oils depends on many factors. Various authors point to the following arguments as a reason for applying one or another oil: suitable fatty-acidic composition of the oils and high oil yield of the seeds, availability of raw materials, use of the oils for food purposes, possibilities of obtaining oils from oil-bearing crops grown in unfavorable climatic zones and soils. The low cost of the product and the sufficient amount of raw materials are also important [3-6].

The main raw materials used for ME production are the following types of vegetable oils: rapeseed, soybean, cottonseed, palm, sunflower [7-18]. An additional source of raw materials is also oils with deteriorated performance. It is known that high quality vegetable oils obtained after appropriate refining are used for food and industrial purposes [19]. The waste products after using the oils in various areas are thrown away or used as animal feed. The same is observed when the quality of raw materials deteriorates due to improper storage or processing. In the interest of maximum and efficient utilization of vegetable oils, these waste products could also be used as diesel engine fuels after appropriate processing. In addition, the use of low-quality raw materials significantly reduces the price of the final product, which is a sought-after effect in the production of alternative fuel for diesel engines [20-23].

2.1 Homogeneous alkaline catalysts

For the preparation of alkyl esters of the higher fatty acids, most authors point to alkaline catalysts as the most suitable [24-26]. The reasons for this are: low reaction temperature and atmospheric pressure, high conversion rate in short reaction time, etc. [27]. NaOH, NaOCH3, KOH and KOCH3 are considered the most effective alkaline homogeneous catalysts [24-35].

Table 1 lists some of the conditions for transesterification of various oils with alkaline catalysts.

Table 1. Conditions for carrying out transesterification of various oils with an alkaline catalyst

Type of vegetable oil	Acid value mg KOH/g	Catalyst % (w/w)	Temp (°C)	Molar ratio (mol/mol)	Time (h)	Yield % (w/w)	Src
Soybean oil	<1	0,5 % NaOCH3\ 1%NaOH	60	60:1	1h	98%	[30]
B.carinata oil	2.2% free fatty acids	1,4 % KOH	25-45	4.6:1	0,5.	98%	[42]
Rapeseed oil	---	1% KOH	65	6:1	2	96%	[43]
Palm oil	0,1	1% KOH	60	6:1	1	99%	[37]
Palm oil	<1	1% KOH	60	6:1	0.5	78%	[44]
Rapeseed/ Soybean oil	< 2	0.8 % NaOH	55	5:1	2	94%	[10]
Sunflower oil	<1	1.3 % KOH	25	6:1	1	98,4%	[29]
Rapeseed oil	<1	0.6 % KOH	50	6:1	1.5	97%	[43]

In practice, the alkali-catalyzed transesterification reaction is about 4000 times faster than the acid-catalyzed transesterification [30]. However, the use of alkaline catalysts is related to the requirements that the oils have a low content of free fatty acids and water [36].

Table 2 lists the main advantages and disadvantages of alkali-catalyzed transesterification [31].

Table 2. Advantages and disadvantages of the alkali-catalyzed transesterification.

Advantages	Disadvantages
- Low cost; - High reaction rate; - High catalyst activity; - "Softer" conditions for carrying out the reaction compared to acid-catalyzed transesterification; - Low energy consumption; - High quality of the final product.	- Requires a minimum amount of free fatty acids; - The reaction is sensitive to the presence of water; - Formation of soaps - if the free fatty acids are over 2%; - Low yield of alkyl esters due to emulsion formation; - A large amount of waste water during washing; - Irrecoverability of the catalyst.

2.2 Mechanism of alkaline transesterification

The alkali-catalyzed transesterification of vegetable oils with alkyl alcohol is a fast and highly efficient process in which the trivalent alcohol glycerol is replaced stepwise by a monovalent alkyl alcohol (most often methyl and ethyl alcohol). This takes place in three stages, each of which separates the corresponding alkyl ester:

Triacylglycerol ↔ Diacylglycerol - First step

Diacylglycerol ↔ Monoacylglycerol - Second step

Monoacylglycerol ↔ Glycerol - Third step

The reactions of each of the steps are reversible, which necessitates the use of a stoichiometric excess of alcohol relative to acylglycerols - to pull the balance of the process to the right to increase the amount of product, according to the law of mass action.

Alkaline catalysts are primarily bases or alcoholates, such as potassium or sodium hydroxides, and their alkoxides.

The alkali-catalyzed reaction proceeds with a high yield of alkyl esters at a relatively low alcohol excess, low catalyst concentration, and low temperature. This makes this type of catalysis particularly preferred, but there is a limitation in its use because at high acidity of the starting raw materials, the catalyst is deactivated and forms soaps with the corresponding fatty acids. Together with the water separated in the process, they give soapy emulsions, which also cause large losses of the target product. To avoid this, a combined approach is most often used, in which the raw materials are pre-treated by an acid-catalyzed esterification method, which is significantly more effective in the presence of free fatty acids, and after the reduction of the latter to the required levels, basic catalysis is applied. At the same time, it is of interest to check how far the possibilities of alkaline transesterification alone extend at high contents of free fatty acids in the starting oil.

2.3 Mixed type homogeneous catalysis

For oils with a high fatty acids content, some authors suggest a two-stage reaction. In the first stage, the acid number is reduced below 1% of free fatty acids based on acid esterification with methyl alcohol, and in the second, alkaline transesterification is carried out (KOH and $NaOCH_3$ catalysts). In this way, the duration and consumption of raw materials in the process of esterification of free fatty acids is reduced and, accordingly, the amount of soaps is significantly reduced due to the removal of soaps (free acids) in the alkaline process of transesterification and the subsequent purification of the final product [37-40].

The use of this method makes it possible to completely convert the starting raw materials into the corresponding alkyl esters, but the presence of many stages leads to greater technological losses of the product, prolongs the time and makes the process more expensive due to high energy consumption.

3 Materials and methods

3.1 Methodology

The following materials were used to achieve the set goal and fulfill the intended tasks: cold-pressed unrefined rapeseed and sunflower oils. Their physico-chemical properties are presented in Table 3. Methyl alcohol (99.9%) was provided by Brentag Ltd.; the potassium hydroxide (KOH, 99.9%) and sodium hydroxide (NaOH, 99.9%) were obtained from Merck, Darmstadt, Germany; phosphoric acid (H_3PO_4, 85%) as well as anhydrous sodium sulfate (Na_2SO_4) were provided by Himtex Ltd., Dimitrovgrad.

The following reagents were used to analyze the products:

- ethyl alcohol (96%) ("Himtex" Ltd., Dimitrovgrad);
- petroleum ether (Bp. 45-55^{o}C) ("Himtex" Ltd., Dimitrovgrad);
- diethyl ether (Bp. 34-35^{o}C) ("Himtex" Ltd., Dimitrovgrad);
- hydrochloric acid (HCl 37%) (Merck, Darmstadt, Germany);
- periodic acid (H_5JO_6, dihydrate: $HJO_4.2H_2O$) (Merck, Darmstadt, Germany).

Table 3. Physico-chemical properties of vegetable oils.

Characteristic	Measuring units	Sunflower oil	Rapeseed oil
Acid value	mg KOH/g	80.1	15.8
Saponification value	mg KOH/g	189.4	190.3
Viscosity	mm2/s	41.9	40.8
Density	g/cm3	0.925	0.920

The following methods for analysis of raw materials exist:

- **BDS EN ISO 3657:2023** Animal and vegetable fats and oils. Determination of saponification value **(ISO 3657:2023**);

- **BDS EN ISO 6320:2017** Animal and vegetable fats and oils. Determination of refractive index (**ISO 6320:2017**);

- **BDS EN ISO 660:2020** Animal and vegetable fats and oils. Determination of acid value and acidity (**ISO 660:2020**);

- **BDS EN ISO 3596:2004** Animal and vegetable fats and oils. Determination of unsaponifiable matter. Method using diethyl ether extraction (**ISO 3596:2000**);

- **BDS EN ISO 3675:2004** Crude petroleum and liquid petroleum products. Laboratory determination of density. Hydrometer method (**ISO 3675:1998**);

- **BDS EN ISO 3104:2024** Petroleum products - Transparent and opaque liquids - Determination of kinematic viscosity and calculation of dynamic viscosity (**ISO 3104:2023**);

- **ST of SIV 1496:1979** Petroleum products. Determination of flash point. Marcuson open cup method. Amendment 1: 1984. Amendment 2: 1985.

3.2 Alkali-catalyzed transesterification of vegetable oils with high acid value

The transesterification was carried out using methyl alcohol with the same molar ratio of oil/CH_3OH = 1:6 in all experiments.

The amount of vegetable oil in the reaction mixture in all experiments was 450 g. Temperature of transesterification process: 35-40°C.

The object of the study was a product of an 8-hour acid transesterification of vegetable (rapeseed) oil with high acid value (AV), using sulphomass as a catalyst.

The conditions of the experiment were in accordance with the recommendations for carrying out alkaline transesterification for oils with relatively high acidity [18]: product weight - 450 g, oil/CH_3OH molar ratio - 1:6, process temperature 35-40°C, the duration of transesterification (time of the process) - 2h, catalyst – KOH – 5.5 g, the amount of the catalyst – 1.5% of the mass of the oil + an additional amount, according to the stoichiometric calculation to compensate for the free fatty acids in the composition of the raw material, expressed as acid value.

3.3 Experimental procedure

In a double-necked round-bottomed flask equipped with a mechanical stirrer, a reflux condenser and a water bath to maintain a constant temperature, the estimated amount of vegetable oil is placed, which is tempered to the desired temperature. A previously prepared solution of catalyst in methyl alcohol is added to it, and the amounts of oil, alcohol and catalyst are in accordance with molar ratios between the reacting substances and the required amount of catalyst set in advance for the relevant experiment. The transesterification process takes place under constant stirring, respecting the preset time and temperature.

After completion of the reaction, the products are transferred to a separatory funnel and left to stand for 24 h to separate them into two phases. The upper phase contains hydrophobic products (mainly the esters of higher fatty acids), and the lower phase is a mixture of glycerol, excess alcohol, catalyst and hydrophilic side products of the reaction. Certain amounts of by-products such as mono-, di-, and triglycerides, alkaline soaps and unsaponifiable products, in alkaline catalysis may also be contained in the ester phase, from which they are removed by washing.

The two phases were decanted as the lower phase, which contains mainly glycerol, excess methanol, catalyst and other hydrophilic reaction products is separated and, if necessary, analyzed for the amount of free glycerol, soaps and unreacted triglycerides.

The phase containing methyl esters passes into a conical vessel for a primary wash with water. The washing is carried out carefully, without intensive stirring, as the water is supplied dropwise on the surface of the phase. The amount of water is no more than 15

vol.% relative to the volume of the ester phase. The ester phase is then decanted from the aqueous layer, and the latter can also be analyzed for soaps and non-esterified glycerides.

The obtained methyl esters are washed again with a 0.03% solution of H_3PO_4, aiming for the pH of the washing waters to be around 3. A third wash with water follows and standing for 24 hours for complete phase separation.

The washed ester phase was dried over anhydrous Na_2SO_4 desiccator for 24h, filtered and analyzed.

3.4 Methods for analysis of methyl esters

To determine the suitability of the obtained methyl esters to be used as an alternative diesel fuel, they were analyzed according to the EN 14214 biodiesel fuel quality standard as follows:

- **BDS EN 14103:2020** Fat and oil derivatives. Fatty acid methyl esters (FAME). Determination of ester and linolenic acid methyl ester contents (**EN 14103:2020**);

- **BDS EN ISO 660:2020** Animal and vegetable fats and oils. Determination of acid value and acidity (**EN ISO 660:2020**);

- **BDS EN ISO 3675:2004** Crude petroleum and liquid petroleum products. Laboratory determination of density. Hydrometer method (**ISO 3675:1998**);

- **BDS EN ISO 3104:2024** Petroleum products. Transparent and opaque liquids. Determination of kinematic viscosity and calculation of dynamic viscosity (**ISO 3104:2023**);

- **BDS EN ISO 2719:2016** Determination of flash point. Pensky-Martens closed cup method (**ISO 2719:2016**);

- **BDS EN ISO 20846:2020** Petroleum products. Determination of sulfur content of automotive fuels. Ultraviolet fluorescence method (**EN ISO 20846:2019**);

- **BDS EN ISO 10370:2014** Petroleum products. Determination of carbon residue. Micro method (**ISO 10370:2014**);

- **BDS EN 14111:2022** Fat and oil derivatives. Fatty acid methyl esters (FAME). Determination of iodine value (**EN 14111:2022**);

- **BDS EN ISO 12937:2003** Petroleum products. Determination of water. Coulometric Karl Fischer titration method (**ISO 12937:2000**);

- **BDS EN ISO 2160:2004** Petroleum products. Corrosiveness to copper. Copper strip test (**ISO 2160:1998**);

- **BDS EN 116:2015** Diesel and domestic heating Fuels. Determination of cold filter plugging point. Stepwise cooling bath method (**EN 116:2015**)

4 Results and discussion

The object of the study was a product of an 8-hour acid transesterification of rapeseed oil, using sulphomass as a catalyst, with following characteristics (parameters, indicators): AV – 2.22 mg KOH/g, viscosity at (40°C) – 18.79 mm^2/s, density at 15°C – 0.902 g/cm^3 and color – 2.

The obtained results are presented in Table 4. For comparison some biodiesel parameters required by EN 14214 standards are also presented.

Table 4. Characteristics of biodiesel samples obtained from vegetable oils with high acid value

Characteristic	Measuring units	Measured value	EN 14214	Test method
Ester content	% (m/m)	93.4	> 96.5	EN 14103
Density at 15˚C	kg/m3	0.885	860 - 900	EN ISO 3675/ EN ISO 12185
Viscosity at 40˚C	mm2/s	4.81	3.5 – 5.0	EN ISO 3104
Flash point	˚C	163	> 101	EN ISO 2719/ EN ISO 3679
Sulfur content	mg/kg	9.22	<10	EN ISO 20846/ EN ISO 20884
Carbon residue (at 10% residual distillate)	% (w/w)	0.42	<0.3	EN ISO 10370
Acid value	mgKOH/g	0.64	<0.5	EN 14104
Iodine value	-	108	<120	EN 14111
Water content	mg/kg	330	<500	EN ISO 12937
Corrosiveness to copper (3h at 50˚C)	level	Class1	Class1	EN ISO 2160
Cold filter plugging point	ºC	Minus 8	-	EN ISO 116

As can be seen from the table, the content of methyl esters is 93.4%, and according to the EN 14214 standard, this content should be a minimum of 96.5%, which tells us that it is necessary to work in the direction of increasing yields. In turn, the density of the product is 0.885 kg/m^3, which corresponds to the quality requirements of biodiesel, according to standard EN 14214. The viscosity at 40°C is also within the norms and is 4.81 mm^2/s. The flash point is 163°C, and the minimum flash point, according to the EN 14214 standard, should be 101°C. The values of the indicators that do not meet the quality requirements of the obtained biodiesel fuel are: carbon residue (at 10% residual distillate) which is 0.42% as required by the standard, less than 0.3% by weight; acid number – 0.64 mg/KOH/g. oil, if required by the standard <0.5 mg/KOH/g. butter. The iodine number, which is 108, is also within the norms, which according to the standard should be below 120. This also applies to the water content, which is 330 mg/kg with norms according to the standard below 500 mg/kg. Another two of the parameters such as corrosiveness to copper for 3h at 50˚C (Class1) and cold filter plugging point (Minus 8) also meet the standard requirements.

Data from Table 4 show that most parameters: viscosity; density; water content; sulfur content; flash point; iodine value; corrosiveness to copper and cold filter plugging point fully meet the requirements of the BDS EN 14214 standard for biodiesel quality. From the investigated characteristics, the carbon residue and the acid value are slightly above the norm, whereas ester content is below the norm, as it is necessary to direct efforts to overcome these shortcomings in the parameters of the obtained biodiesel fuel.

The presented works regarding the production of biodiesel consider the different conditions for the synthesis of methyl esters of fatty acids. In the first paper, the acid-catalyzed esterification and transesterification reaction of low quality (high acid number) vegetable oils was investigated using sulfoma, p-toluenesulfonic acid and tetraethyltitanate as acid catalysts. The second paper examines the alkali-catalyzed transesterification reaction of a product of an 8-hour acid esterification and the transesterification of a low quality vegetable oil with a high acid number using an alkaline base as a catalyst. Based on the presented research, it is concluded that in order to obtain quality biodiesel fuel, it is necessary to carry out a two-stage transesterification of low-quality vegetable oils with high acid numbers.

Other methods for the preparation of methyl esters of acids are disclosed in the works 45-51. Also, the works 49-55 present methods and conditions for the preparation of other esters of acids, i. e. cyanomethyl activated esters [49-53] and esters with polyvalent alcohols [49-55].

5 Conclusion

The obtained results allow us to make the following main conclusions:

1. The direct use of vegetable oils as diesel fuel in modern diesel engines is inexpedient due to the structural and technological orientation of the combustion process towards petroleum hydrocarbons, which have very different physicochemical properties from vegetable oils;
2. Several methods have been developed to adapt vegetable oils to combustion in diesel internal combustion engines, the most promising of which is the pre-esterification of the triacylglycerols contained in them with lower fatty alcohols, in which products (esters) with physicochemical properties very close to those of mineral diesel fuel;
3. A wide range of vegetable oils are used as raw material for obtaining esters of higher fatty acids - fresh (crude pressed, unrefined and refined), waste - with deteriorated physicochemical properties after use for other purposes or due to improper storage. An advantage of vegetable oils is their renewable nature, while a serious disadvantage is their limited quantities and high price;
4. Different methods for transesterification of vegetable oils have been developed, of which the processes of homogeneous acid and alkaline catalysis are most widely applied;
5. Transesterification with an alkaline catalyst is more effective, respectively cheaper, compared to the acid-catalyzed process. However, it is limited by the content of free fatty acids in the starting vegetable oils due to side side reactions that sharply reduce the yield of the target product – alkyl esters of fatty acids;
6. It is expedient to carry out research and look for ways to improve the pre-esterification of vegetable oils with a view to making the produced esters cheaper and improving their parameters, as well as expanding the raw material base for their production.

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