This paper reports results of the theoretical and experimental studies into the processes of transesterification of oils with methyl alcohol, which determined the material balance and established the molecular weight of the components involved in the process of transesterification as input and output products. The theoretical and experimental studies were carried out to calculate the indicators of the process of transesterification of fat-containing wastes depending on a change in the reaction duration and diameter of the inertial mixer of the reactor to accelerate the process of transesterification of oils with methyl alcohol.

The process of transesterification is one of the basic methods for modifying the molecular composition of fat raw materials. With transesterification, the composition of fat fatty acids does not change, their statistical redistribution occurs in a mixture of triacylglycerols, which leads to a change in the physicochemical properties of fat mixtures as a result of changes in molecular composition. Transesterification of high-melting animal and vegetable fats with methyl alcohol improves the conversion of oils for the production of biodiesel from fat-containing waste.

The results of the theoretical and experimental studies have helped determine the value of the flow rate of the reaction mixture, as well as the values of the geometric dimensions of the reactor, were determined (the diameter of the mixer, d=100÷500 mm; the length of the reactor is 1.5÷2.0 m). Processing of the reaction mixture made it possible to obtain a high degree of homogeneity in the concentration of components with large diameters of the inertial mixer – 300...500 mm at average rotational speeds. The oil conversion has been improved, as well as productivity, by using equipment to produce biodiesel from fat-containing waste. Optimal pump performance is also ensured with minimal power consumption and reactor operation

Keywords: transesterification processes, biodiesel production, diesel internal combustion engines, emission reduction

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SUBSTANTIATION OF PARAMETERS FOR THE INERTIAL MIXER IN A BIODIESEL PRODUCTION REACTOR

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1. Introduction

The intensive development of industry and transport infrastructure under the conditions of modern megacities in the world has led to a deterioration in the environmental stresses involving the influence of greenhouse gases. One of the most promising solutions to this problem is the use of alternative fuel for diesel engines.

Given the fuel crises and the adoption of strict standards regarding the toxicity of exhaust gases in developed countries, intensive research has been conducted in recent years. New technologies are being introduced to produce fuel for use in carburetor and diesel engines from renewable energy sources.

Biodiesel was first suggested by Englishmen Duffy and Patrick. Only 40 years later, the German scientist Rudolf Diesel invented an engine running on peanut butter. Diesel fuel at that time was cheaper, so it became, for many years, the main type of fuel for diesel equipment [1].

Transport biofuels exist mainly as ethanol and biodiesel. In 2014, ethanol accounted for 74 % of the transport biofuel market, biodiesel for 23 % (mainly in the form of fatty acid methyl esters), and hydrogenated vegetable oil (HVO) for 3 %. These fuels are made from food raw materials. Ethanol is obtained from sugar cane (61 %) and grain (39 %). The main raw materials to produce biodiesel are soybeans and rapeseed. Attempts to commercialize liquid biofuels from sources that do not compete with food production have not yet led to statistically significant market results. Based on the above, we consider issues related to the production of biodiesel fuel from fat-containing waste.

The conventional method of obtaining biodiesel fuel involving the catalytic (homogeneous catalysis) transesterification reaction is mainly implemented in the temperature range of 60–67 °C under atmospheric pressure and a molar ratio of "alcohol/oil" equal to 6:1. The duration of the reaction, varying in the range from 1 to 20 hours, is determined mainly by the nature of the catalyst (acidic or alkaline).

The main disadvantages of this technology include excessive process time, the formation of unwanted saponification products, the need to clean the reaction product from the catalyst, as well as the bulkiness of the equipment used. A significant shortcoming of technologies using a catalyst are the removal of the catalyst from the cycle in general, as well as from the products of its interaction after the reaction, which is important for simplifying the production technology and purity of the resulting target product.

The conventional process of obtaining biodiesel fuel is associated with the immiscibility of the starting reagents, a small contact area and, as a result, a low rate of chemical reaction; with the improvement of the production process, the acceleration of the transesterification reaction becomes an urgent problem in the production of biodiesel fuel. The mechanisms of acceleration of the process of re-esterification and selection of rational technological parameters of production are considered.

2. Literature review and problem statement

Homogeneous alkaline catalysts NaOH, KOH, CH_3ONa, and CH_3OK are used to conduct experimental studies into the transesterification of vegetable oils in the production of biodiesel fuel [1]. However, due to the high cost of refined raw materials and the difficulties associated with the use of homogeneous alkaline catalysts in the transesterification of low-quality raw materials, biodiesel synthesis at elevated pressure and temperature may be a promising technology. Processing of waste oil after frying reduces the impact on the environment [2], however, the reported thermodynamic data, phase equilibria, kinetic parameters, and modeling did not resolve the issue of accelerating the reaction.

Transesterification makes it possible to obtain new types of food fat products with specified properties [3] and allows the adjustment of the content of highly melting fatty acids in food fats. Transesterification leads to a decrease in the melting point of fat or a mixture of fats, increasing their plasticity and stability to oxidation by oxygen in the air.

The main features of transesterification are ease of process control, process automation, ease of operation, and reduced hazards. Automation is used to reduce the hazards associated with human error, achieve higher and more consistent quality, higher outputs, reduce consumable consumption, as well as a higher degree of safety.

Methoxide and oil are supplied to the input of the module. Sequentially connected volumes ensure the impossibility of penetration of non-reacted components to the output of the module with the continuous mixing and flowing nature of the module operation. The ether-glycerin mixture obtained in the module is fed into the gravitational separator.

Paper [4] reports the results of research into the production of biodiesel from fat-containing waste. To accelerate the transesterification reaction, separation is carried out by deposition of a denser glycerin phase under the influence of gravity. A vertical settler is a periodic settler. Under this technique for activating the transesterification reaction in the production of fatty acid esters, including the reaction of vegetable oil with alcohol in the presence of a catalyst, hydrodynamic mixing is used. This activates the standard centrifugal pump due to the energy of the rotating rotor, at a rotor rotation speed of 1,200–2,600 rpm and a temperature of 57 °C.

The mixing of normalized flows of starting components is enabled by the rotor of the centrifugal pump-activator, consisting of a rotor, walls of a pump housing. At the same time, it was established that with the width of the pump blades from 0.015 m to 0.025 m, the capacity Q=0.8 m^3/h was achieved, at minimal energy consumption, as well as the completeness of mixing of components and an increase in the speed of the transesterification reaction.

The completeness of the transesterification reaction is achieved at a heating temperature of the mixture of 50...80 °C and at critical mixing speed (1.75 V_{cr} to 2.0 V_{cr}), which ensures optimal pump performance with minimal energy consumption and improves the performance of the reactor [5]. These indicators of the equipment make it possible to slightly accelerate the transesterification process of unrefined vegetable oils, animal fats, residues of vegetable and culinary fats after cooking, residues of melted animal fats of the meat industry.

A new method has been proposed by scientists at the Tokyo University of Technology for converting vegetable oil into biodiesel with a catalyst that is 10–50 times cheaper than the chemicals currently used [6], but the reaction rate remains unchanged.

Works [7, 8] report the results of studying the process in line with the alkaline method based on the “Saka method” for the production of the 2nd generation of biodiesel with supercritical methanol. The cited works are aimed at increasing the productivity of biodiesel but the rate of chemical reactions remains the same.

It should also be noted that the processes of obtaining biodiesel fuel with the processing of food waste into useful products for urban transport remain a task to be studied. The results of the theoretical and experimental studies reported here aim to establish optimal indicators of equipment and working processes in the production of biodiesel fuel.

3. The aim and objectives of the study

The purpose of this study is to determine the rational technological parameters for the inertial mixer of the reactor to produce biodiesel. This will make it possible to speed up the process of transesterification in the production of biodiesel from fat-containing waste.

To accomplish the aim, the following tasks have been set:

– to substantiate the rationality of the technological parameters for the equipment to produce biodiesel from fat-containing waste;

– to increase the reaction rate of transesterification with the improvement of the technological process and increasing the yield of the product.

4. The study materials and methods

We have applied classical scientific methods based on the study of existing world practice and experience in this industry, as well as our observations, and actual data from scientific experiments considering the results of experimental practical application.

A systematic approach is used as a basis for investigating the examined object: an integrated complex of interrelated elements; a set of interacting objects; a totality of essence and relationships. The method makes it possible to organize actions, identify patterns and interdependences, in order to utilize them more effectively.

The studied alkaline process involves the production of the 2nd generation of biodiesel using a two-stage supercritical method of methanol [9] and is aimed at increasing the productivity and reliability of the biodiesel production process.

Devising biodiesel production technology involves the use of waste vegetable and animal fats for the preparation of mixed biofuels, from the cheapest raw materials (residues of vegetable oils after cooking), which increase the efficiency and "environmental friendliness" of the diesel engines (ICE) in vehicles. The French manufacturer of engines for military equipment *Safran* substantiated the performance indicators of biofuel power units. And the head of the defense ministry noted that the army would reduce the consumption of conventional fuels in the following years by 20 % [10].

To establish the optimal parameters for the oil transesterification process, we calculated parameters for the inertial mixer of the reactor in terms of the consumption of starting components, which are adjusted depending on their quality [7, 8]

$$V_k \rho_k = V_1 \rho_1 + V_2 \rho_2,$$

where V_k is the resulting volume, m^3;

ρ_k – resulting density, kg/m^3;

V_1 – the volume of liquid 1, m^3;

ρ_t – density of liquid 1, kg/m^3;

V_2 – the volume of liquid 2, m^3;

ρ_2 – density of liquid 2, kg/m^3.

To increase the oil (hydrocarbon base) content for oil/water, the current water content was changed to a new volume percentage for oil/water

$$V_{new.hc} = \frac{W_{pr.w}}{W_{new.w}},$$

where $V_{new.hc}$ is the new volume of the mixture "hydrocarbon base–water", m^3, while maintaining a constant value of water content; $W_{pr.w}$ – primary water content, m^3; $W_{new.w}$ is the new water content, %, in drilling mud

$$V_{add} = V_{pr.w} - V_o,$$

where V_{add} is the volume of water to be added, m^3; $V_{pr.w}$ is the primary volume of the mixture "hydrocarbon base–water", m^3.

To increase the water content in the oil–water ratio, the current oil content must be replaced with a new volume

$$V_{new.hc} = \frac{W_{pr.w}}{W_{\%}},$$

where $V_{new.hc}$ is the new volume of the mixture "hydrocarbon base-water" while maintaining a constant value of the content of the hydrocarbon base;

$W_{new.hc}$ – the primary content of hydrocarbon base (oil) per m^3 of drilling mud;

$W_{\%}$ is the new content of hydrocarbon base (oil) in % (fractions of unit).

The amount of water to be added is calculated as follows:

$$W_W = V_{pr.w} - V_o,$$

where W_w is the volume of water to be added, m^3.

The main indicator of the operation of the inertial mixer of the reactor is the homogeneity of the mixture, which assumes that all its components should be evenly distributed throughout its volume. That is, samples of the mixture (or individual samples taken from the mixture) should have the same quality indicators. In practice, such an ideal mixing cannot be achieved, especially when it comes to any micro additions, since the mixing of the components of the mixture is influenced by a huge number of different factors.

An infinite variety of interposition of individual particles is possible, so the ratio of components at any point in the mixture is a random variable. As a result, modern methods for assessing the effectiveness of mixing (that is, the quality of the mixture) are based on statistical analysis methods.

Since its laws for systems with many random variables are very complex, in practice the quality of mixing is estimated by the distribution of one of the components, for which the mixture is conditionally considered two-component. The most widespread as a criterion for assessing the quality of mixing is the coefficient of variation (heterogeneity)

$$V_c = \frac{100}{x} \sqrt{\frac{\sum_{i=1}^{i=n} (x - x)^2}{n-1}},$$

where x is the arithmetic mean of the values of the quantity, that is, the average content of a key component in the samples;

y – the value of a random variable in the i-th sample;

n – the number of samples taken.

If the values $(v-y)$ tend to zero, then the value $Vc>0$, that is the quality of mixing would increase. To assess the quality of mixing, the following indicators are adhered to: if $VC<3$ %, the mixture quality is excellent; at 3 %$<VC<$7 %, it is good; at 7 %$<Vc<$15 %, it is fair; at $Vc>15$ %, it is bad.

The components are mixed in mixers of periodic and continuous action. The choice of mixers depends on the techniques for introducing (dosing) the components into the mixture. When using batch dispensers, periodic mixers are also used. With continuous dosing, mixing is carried out in continuous mixers [9, 10].

Mixing is more effective in the case where these properties are close enough to each other. Greater differences in density and size contribute to particle segregation. The number of components and their ratio are also significant. With an increase in the number of components, their share decreases, the mixing process is difficult. Especially increased is the duration of mixing in the presence of components that are included in the mixture in small quantities.

An alternative to the periodic mixing technique is continuous mixture formation. In this case, random and ordered mixing methods are combined. An ordered method of mixing takes place when the initial components are fed into the mixer by dosing devices. Directly in the mixer, the mixing of the components entering it is random.

Under normal conditions, the reaction of oil and ethanol transesterification occurs in the emulsion where the continuous phase is ethanol, and the dispersed phase is fatty acid triglycerides. The chemical reaction takes place at the interface of the phases, that is on the surface of the droplet. Given that the rate of the chemical reaction of transesterification is not high, the course of the chemical transformation process will be significantly influenced by the speed of supply of components to the interface of phases and the removal of reaction products from it. Thus, the chemical transformation would occur in the mixed region. Studies of the similarity conditions of the processes of diffusion chemical kinetics found that, in this case, for a large-scale transition it is necessary to take into consideration the similarity of all stages of the process, which is quite difficult when changing the scale of the apparatus.

5. Studying equipment parameters to accelerate transesterification in the production of biodiesel from fat-containing waste

5. 1. Refining the rational technological parameters of equipment to produce biodiesel from fat-containing waste

We measured equipment indicators in a laboratory installation (Fig. 1), with the help of measuring instruments, during operation as close as possible to production. Measuring instruments and equipment include a liquid pressure gauge 1 for measuring the pressure created in the system (mm Hg), a fluid 2 flow meter (m^3/h), a tachometer for measuring the number of revolutions of the shaft 3 (rev/min). There is also a three-phase electric current meter 4 (kW/h).

Biodiesel fuel is produced at a laboratory sample of mobile equipment on the basis of transesterification reactions. The main components for the course of this transesterification reaction are raw materials containing fat-containing waste, methanol (methyl alcohol), and a catalyst (caustic soda). In the beginning, 200 liters of the raw materials are heated to 57 °C in a tank for oils (fat-containing waste) by electric heating elements of 3.2 kW, over 40 minutes. Simultaneously, we mix, in the methoxide unit, 1.5 kg of the catalyst (caustic soda) with 36 liters of methanol (methyl alcohol): at these proportions, such a reaction takes 10–15 minutes. Next, the heated raw materials, mixed with methanol and catalyst, are sent to the reactor through an inertial mixer for the synthesis of biodiesel fuel by a pump.

Next, a pump-activator hydrodynamically mixes these components with an inertial mixer to a homogeneous mass for 5–10 minutes. The transesterification reaction takes about 30 minutes; the mixed mass is sent to the unit for the finished product.

Thus, one production cycle with 200 liters (98 %) of biodiesel fuel and 32 liters of (dirty) non-purified glycerol lasts about 1 hour and 30 minutes. Subsequently, the resulting mass is settled for the separation of biodiesel fuel and glycerin; for obtaining high-quality biodiesel fuel, washing with hot water from various impurities is carried out.

The results of the analysis of the production process show that when the mobile equipment is operated, approximately 970 kg (1,100 l) of biodiesel and 160 kg of primary (dirty) glycerin are obtained from one ton of fat-containing waste. A mixture of vegetable oil and animal fats and 250 (120) kg of alcohol (in the presence of 10–15 kg of NaOH catalyst) were used in a given process.

5. 2. Accelerating a transesterification reaction rate with process improvement and increased product yield

Our theoretical and experimental studies are aimed at accelerating the reaction and turning the reaction system into a homogeneous one, which greatly simplifies the large-scale transition to industrial installations. When a chemical reaction occurs under homogeneous conditions, the rate of its course is influenced by the concentration of reagents in the reaction zone and temperature. Therefore, in order for the reaction to proceed under the same conditions, it is necessary to create homogeneity in the field of temperature concentrations. As the experimental studies have shown, with such a supply of raw materials to the reactor, it is possible to achieve the best results in conversion and selectivity of chemical transformation.

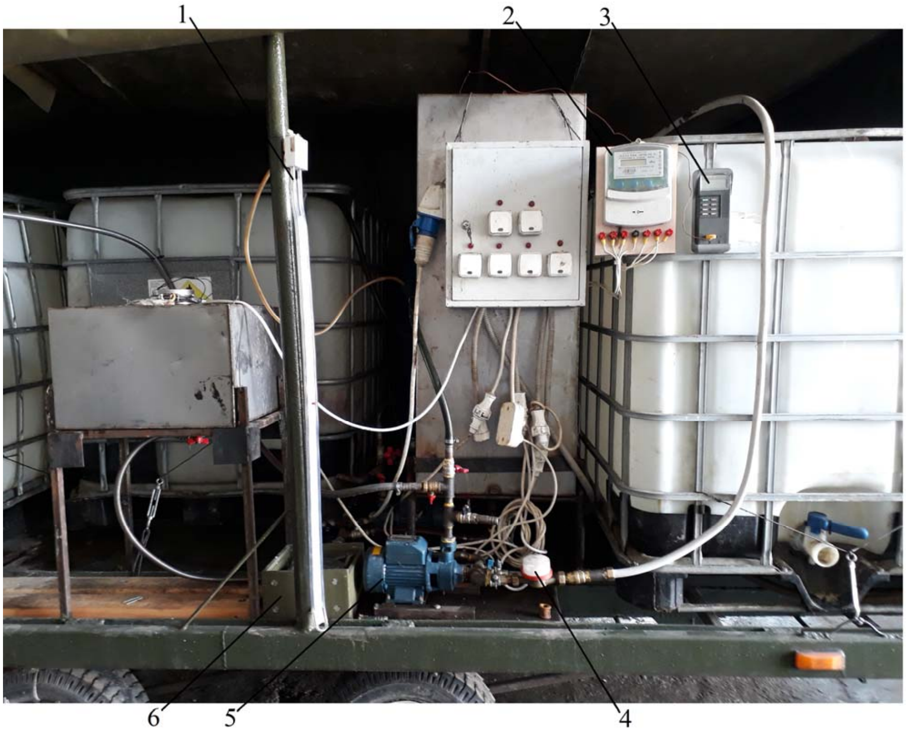

Fig. 1. General view of the laboratory installation: 1 — liquid pressure gauge; 2 — three-phase electric current meter; 3 — electronic thermometer; 4 — liquid flow meter; 5 — tachometer for measuring the number of revolutions of the shaft; 6 — aneroid barometer

To describe the change in the concentration of components by the diameter of the inertial mixer of the reactor in a homogeneous medium, it is necessary to adequately describe the flow structure. For a pipe reactor, it is permissible to use one-dimensional models of the flow structure, for example, diffusion

$$-\frac{\partial C_A}{\partial \tau}= =-W_x\frac{\partial C_A}{\partial x}-D\left(\frac{\partial C_A}{\partial x^2}\right)+W_A,$$

where C_A is the mass concentration of component A in the reaction mixture, kg/m^3;

x is the spatial coordinate, m;

D is the molecular diffusion coefficient, m^2/s;

W_A is the chemical reaction rate, 1/s.

For the conditions of the process in a laboratory mobile reactor with an inertial reactor, the Re and Pe criteria were determined:

$$R_e = \frac{\rho_{mix} W d}{\mu_{mix}} = 14356.4,$$

$$P_e = u_{a.s}\, d / D_{mk} = 0.76 R_e^{0.125} = 2.5,$$

where ρ_{mix} is the mixture density, kg/m^3;

W – the flow rate of the reaction mixture, m/s;

μ_{mix} – dynamic viscosity coefficient of the mixture, Pa·s;

$u_{a.s}$ – the average speed of the environment, m/s;

D_{mk} – mixing coefficient;

d – channel diameter, m.

Based on the obtained values of Re and Pe, it can be concluded that the flow structure is close to the ideal displacement model. For this model, a piston flow is taken without mixing along the flow with a uniform distribution of the concentration of the substance in the direction perpendicular to the movement. Consequently, there are no longitudinal and radial diffusion in the reactor, and the equation is converted to the form:

$$-\frac{\partial C_A}{\partial \tau} = -W \frac{\partial C_A}{\partial l} + W_A,$$

where W is the linear velocity of the reaction mixture in the reactor, m/s;

l is the length of the path traveled by the element of the volume of the reaction mixture in the reactor, m.

The equation is a mathematical notation of the flow of the reagent in an inertial mixer of continuous action under the non-stationary mode. Under a stationary mode, the equation takes the following form:

$$W \frac{\partial C_A}{\partial l} = W_A,$$

with initial boundary conditions: $l=0;\ C_A = C_A 0$.

For a single-stage transesterification reaction of rapeseed oil (TG) in ethanol (Eth) medium to obtain ethyl esters of fatty acids (EEFA) and glycerol (GL):

$$TG + 3Eth = 3_{EEFA} + GL.$$

The kinetic reaction equation of the pseudo-first-order for ideal displacement conditions is written as:

$$\frac{dC_{\mathrm{EEFA}}}{\partial \tau} = \kappa C_{\mathrm{EEFA}}.$$

After determining through calculation the effective constants of the reaction rate under various conditions of the reaction, given in Table 1, we have established the dependence of these constants on the temperature in the form of the Arrhenius equation:

$$k = A e^{-\frac{E_a}{RT}}.$$

In the inertial mixer of the reactor for ideal displacement, the mass concentrations of components at time τ are determined from the following dependences:

$$C_{TG}^{\tau} = C_{TG}^{\tau}\, e^{-k\tau},$$

$$C_{Eth} = C_{Eth}^{0}\, e^{-k\tau}, \left(\tau = 0; C_{Eth} = C_{Eth}^{0}\right),$$

$$C_{EEFA}^{\tau} = \left(\left(C_{TG}^{0} - C_{TG}^{\tau}\right) 3 \frac{M_{EEFA}}{M_{TG}} + C_{EEFA}\right),$$

$$C_{GL}^{\tau} = \left(\left(C_{TG}^{0} - C_{TG}^{\tau}\right) \frac{M_{GL}}{M_{TG}} + C_{GL}^{0}\right),$$

where C_{TG}^{0} is the mass concentration of rapeseed oil at the beginning of the reaction;

C_{Eth}^{0} – the mass of ethanol at the beginning of the reaction;

C_{EEFA} – the mass concentration of EEFA at the previous calculated point in time;

$M_{Eth}, M_{TG}, M_{\mathrm{EEFA}}\ M_{GL}$ are the molar masses of ethanol, rapeseed triglyceride, EEFA, and glycerol, respectively, kg/kmol;

τ – reaction time, s;

k – reaction rate constant (1/s); determined from the Arrhenius equation [5].

Table 1

Effective constants of reaction rates depending on the molar ratio of the mixture "ethanol/rapeseed oil" and temperature, min^{-1}

Molar ratio of the mixture/temperature, °C	6:1	8:1	10:1	12:1	16:1
100	0.054	0.084	0.092	0.121	0.126
160	0.062	0.092	0.121	0.142	0.162
220	0.074	0.104	0.136	0.145	0.174
280	0.078	0.128	0.156	0.162	0.178
320	0.082	0.132	0.186	0.211	0.282
400	0.091	0.146	0.222	0.232	0.291

We calculated the indicators of the process of transesterification of fat-containing wastes depending on the change in the reaction duration and diameter of the inertial mixer of the reactor.

Table 2 gives indicators of the petrification process of fat-containing waste.

The results of calculating the mathematical model of concentration change depending on the duration of the reaction and the degree of transformation on the diameter of the inertial mixer of the reactor are shown in Fig. 2, 3.

Table 2

Indicators of the petrification process of fat-containing waste

Processing time, min	Model concentration, %			
	Oil	Ethanol	EEFA	Biodiesel
0	85	20	3	0
10	35	12	2.5	55
20	15	8	4	75
30	5	5	5	82
40	3	6	5	83
50	1	9	6	85

The model of the ideal displacement reactor makes it possible to solve the task of a large-scale transition from a laboratory installation to industrial production. To recalculate the reactor for high performance, it is necessary to determine the diameter and length of the reactor at the values of the Re and Pe numbers obtained earlier for the laboratory installation.

Based on the values of Re and the value of the flow rate of the reaction mixture, we determined the values of the geometric dimensions of the reactor (the diameter of the mixer, d=100÷500 mm; the length of the reactor, 1.5÷2.0 m). With an increase in the rate of supply of the reaction mixture, the residence time of the reaction mixture inside the inertial mixer of the reactor decreases. Accordingly, the mass content of the target product, EEFA, decreases (Table 3).

Table 3

Element conversion degree

Diameter, mm	Ratio (alcohol/oil)			
	6:1	8:1	12:1	16:1
0	0	0	0	0
100	16	18	28	36
200	36	46	68	78
300	59	72	82	89
400	68	82	88	92
500	72	86	90	94

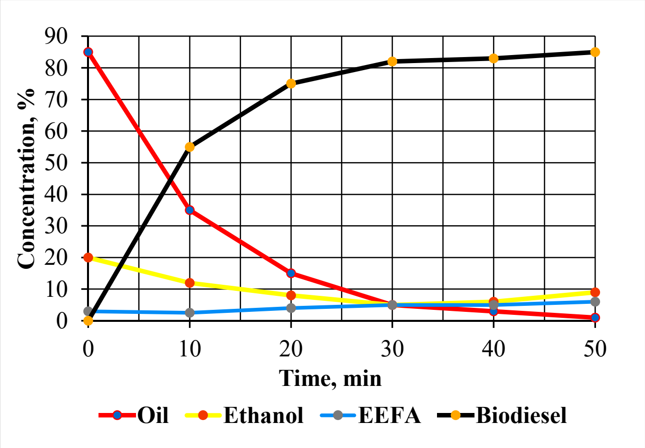

Fig. 2. The dependence of the mass concentration of the components on the duration of the reaction at a molar ratio of 6:1 and T=593 K

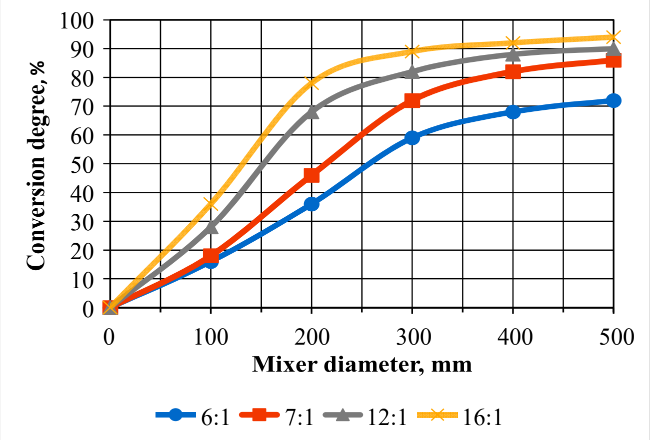

Fig. 3. Dependence of the degree of oil conversion on the diameter of the reactor mixer for different alcohol/oil ratios

At the same time, the pressure loss at the end of the reactor does not exceed 18 kPa. The feed rate of the reaction mixture, at which the pressure loss of the inertial mixer of the reactor is relatively small and, at the same time, the turbulent flow mode is maintained, which provides the necessary mixing of the reagents, is 0.4÷0.6 m/s.

Thus, based on the results of our study, a high degree of oil conversion in biodiesel fuel is provided by the composition of the reaction mixture and the thermodynamic conditions of the process, as well as the hydrodynamic situation in the flow mixing in the reactor.

Pre-treatment of the reaction mixture has made it possible to obtain a high degree of homogeneity in the concentration of components at large diameters of the inertial mixer – 300–500 mm at average rotational speeds. This solution has made it possible to reduce the molar ratio to values from 16:1 to 6:1 without the use of homogeneous catalysts and to increase the conversion of oils compared to the process without pre-treatment.

6. Discussion of results of studying the process of transesterification

To accelerate the process of transesterification in the production of biodiesel from fat-containing waste, we have substantiated rational technological parameters for the equipment involving the improvement of the technological process and an increase in the yield of the product. The values of the geometric dimensions of the reactor were established, which has made it possible to reduce the molar ratio without the use of homogeneous catalysts and increase the conversion of oils compared to the process without pre-treatment.

As a result of the theoretical and experimental studies into effective reaction rate constants under various reaction conditions, given in Table 1, we have established the dependence of these constants on temperature in the form of the Arrhenius equation. Processes in the inertial mixer of the ideal displacement reactor have also been defined, for which the dependences of mass concentrations of components at time τ were determined.

It should be noted that this study has certain limitations for the geometric dimensions of the reactor (mixer diameter, d=100÷500 mm; reactor length, 1.5÷2.0 m), which make it possible to reduce the molar ratio to values from 16:1 to 6:1.

The disadvantage of the study is the large limit to constraint the parameters of the accelerator, which generates an increase in the energy demand of devices. Therefore, in the future, it is advisable to advance the study in the direction of the use of hydraulic mixers to create critical reaction rates.

7. Conclusions

1. We have established the indicators of the petrification process of fat-containing waste depending on the change in the reaction duration and diameter of the inertial mixer of the reactor; as well as the rational value of the flow rate of the reaction mixture. The values of the geometric dimensions of the reactor (mixer diameter, d=100÷500 mm; reactor length, 1.5÷2.0 m) to produce biodiesel from fat-containing waste were determined.

2. The speed of the reaction mixture supply was increased; the residence time of the reaction mixture inside

the inertial mixer of the reactor was reduced; and the mass content of the target product, EEFA, was reduced. We have achieved a high degree of homogeneity in the concentration of components at large diameters of the inertial mixer, 300–500 mm, at average rotational speeds. Increased conversion of oils and productivity of equipment to produce biodiesel from fat-containing waste have been achieved.

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