Research of the hydro-mechanical mixer parameters for diesel biofuel production with using Box-Benghken experiment plan

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Abstract: The aim of the work is determination of influence of the mixture temperature, of the frequency of mixer rotation and of the mixing time on the specific energy consumption of the process of diesel biofuel production with using of the laboratory mechanical mixer, determination of influence of the nozzle diameter, of the rate of turn-over of the pump shaft of the mixture delivery and of the angle of inclination of the blades on the rate of turn-over of the hydro-mechanical mixer and on the specific energy consumption during of diesel biofuel production, and also determination of influence of the amount of potassium methylate added to the oil on the diesel biofuel kinematic viscosity and the endurance time of diesel biofuel with air access on the flash temperature of diesel biofuel. The object of research was the laboratory mechanical mixer for determination of the specific energy consumption of the process of diesel biofuel production and pilot sample of the hydro-mechanical mixer for the diesel biofuel production. The subject of research was determination of energy parameters of the process of diesel biofuel production and of diesel biofuel quality parameters. Experimental studies were conducted with using the Box-Benghken plan, which minimizes the dispersion between the experimental data and the value obtained by regression equation. The regression equations to determine the specific energy consumption of the process of diesel biofuel production with using of the laboratory mechanical mixer and to determine the rate of turn-over of the hydro-mechanical mixer and the specific energy consumption of diesel biofuel production with using of the pilot sample of the hydro-mechanical mixer are obtained. The dependence of the influence of the nozzle diameter, the rate of turn-over of the pump shaft of the mixture delivery and the angle of inclination of the blades on the rate of turn-over of the hydro-mechanical mixer is established. The influence of the structural and technological parameters of the hydro-mechanical mixer on the specific energy consumption of diesel biofuel production is determined. The dependencies for determination of influence of the amount of potassium methylate added to the oil on the diesel biofuel kinematic viscosity and the endurance time of diesel biofuel with air access on the flash temperature of diesel biofuel are obtained.

Keywords: nozzle, blade, pump, rate of turn-over, specific energy consumption, kinematic viscosity, flash temperature

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1 Introduction

The limitation of fossil fuel resources encourages the search for renewable fuels and the development of the necessary equipment for their production and use. Significant consumers of diesel fuel resources are agricultural enterprises, which encourages the introduction of innovative energy-saving technologies, including the production of diesel biofuels (Ivanov and Stoyanov, 2016) on the basis of its own raw material base (plant oils) (Golub et al., 2017b). This can ensure energy autonomy of agricultural producers for the consumption of diesel fuel. Since up to 80% of operations in agricultural production are carried out using diesel fuel, the economic efficiency of agricultural production is

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largely determined by its cost (Golub et al., 2017c).

Directive 2009/28/EC of the European Parliament and of the Council of Europe requires an increase in the use of energy from renewable sources to ensure the reduction of greenhouse gas emissions. According to this Directive, the share of energy produced using renewable sources in 2020 should be at least 10% of its final consumption, and the reduction of greenhouse gas emissions should be at least 35%. One of the ways to reduce greenhouse gas emissions is the use of diesel fuel. The use of diesel biofuels reduces emissions of CO, CO_2 and smoke (Jaliliantabar et al., 2017; Hosseini et al., 2017). Also, studies have been conducted on the use of biofuels and nanoparticles to reduce harmful emissions (Dhinesh et al., 2017a, 2018). Known studies to reduce carbon, hydrocarbons and smoke emissions, due to better air motion in the changed depths and forms of combustion bowl in internal combustion engines (Dhinesh et al., 2017b; Lalvani et al., 2015).

In this regard, research in the direction of development and improvement of equipment for diesel biofuel production is an urgent task.

One of the perspective directions of diesel biofuel production is getting it from the oil obtained while pressing grain wastes. There are also models that primarily calculate the nutritional needs of the state population, and secondly – the possibility of diesel biofuel production (Wijaya et al., 2017). Technology of vegetable oil production includes the step of grain cleaning before oil expression. The volume of grain wastes can reach up to 7% of sunflower grain weight (National State Standard of Ukraine 4694:2006), up to 3% of rapeseed weight (National State Standard of Ukraine 4966:2008) and up to 3% of soybean grain weight (National State Standard of Ukraine 4964:2008). The results of calculation of the production potential of diesel biofuel obtained from the oil derived from grain wastes are given in (Table 1) (Golub et al., 2017a).

Table 1 Potential of diesel biofuel production using oil obtained from grain wastes

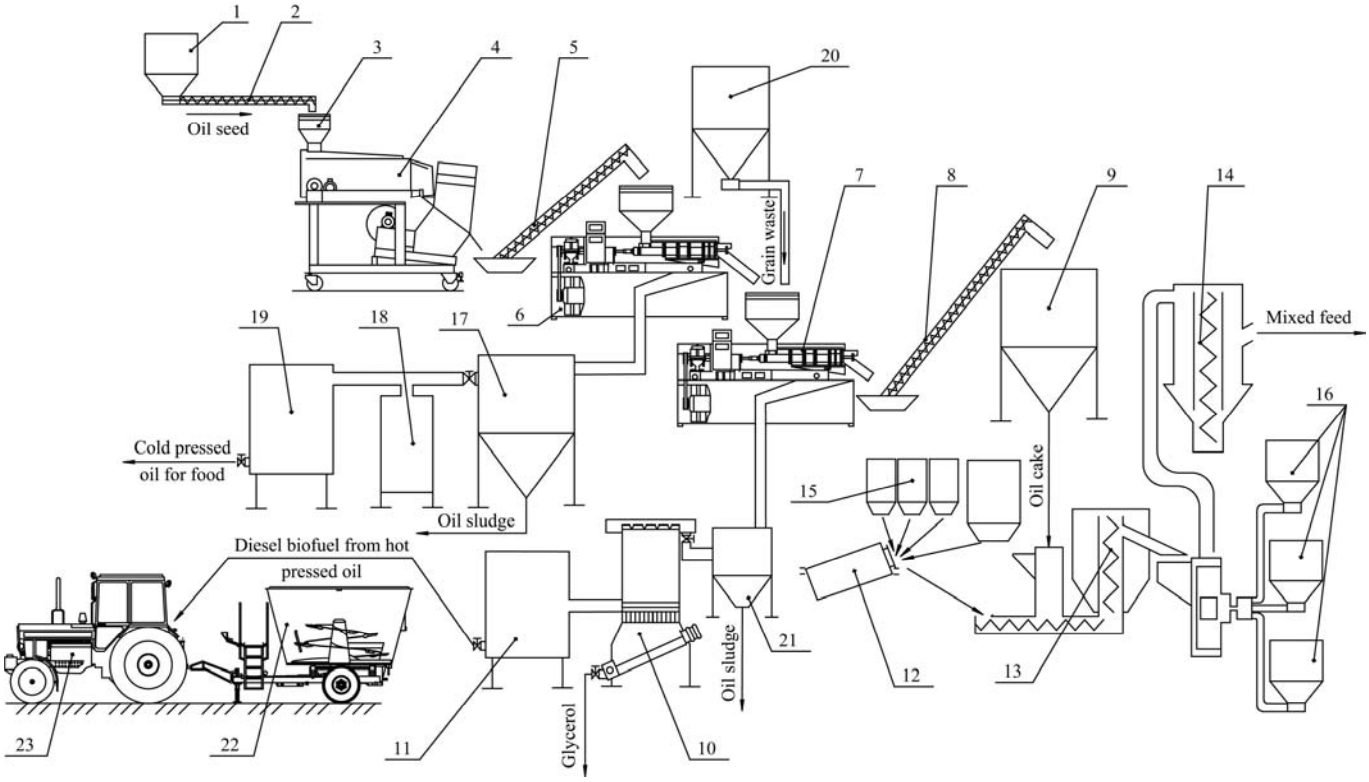
Oil crop	Gross production, thousands of tons	Output						Volumes of diesel biofuel production
		grain wastes		oil mass		oil		
		%	thousands of tons	%	thousands of tons	%	thousands of tons	thousands of tons
Sunflower	11181.1	7	782.7	20	156.5	60	93.9	79.8
Soybean	3930.6	3	117.9	20	23.6	60	14.2	12.0
Rape	1737.6	3	52.1	20	10.4	60	6.3	5.3
Total	16849.3	952.7		190.5		114.3		97.2

The technological scheme of two-stage extraction of vegetable oil and production of diesel biofuel is shown in Figure 1. After getting the oil using cold pressing the cake still contains oil components. Therefore, further, this cake and grain wastes are sent to the hot-press extruder, where oil is obtained, which is advisable to use for the production of diesel biofuel.

The technological process of diesel biofuel obtaining at the same time is advisable to perform using agro-industrial technology. The advantages of this technology include: lower energy consumption in comparison to industrial technology, availability in use, lower costs of chemical reagents, smaller size of the equipment. Besides, the advantages include low cost of production, and the lack of technological operation of washing with subsequent dehydration of diesel biofuels, which in turn reduces energy consumption (Pavlenko, 2013).

During the biodiesel production the mixing process to ensure the transesterification of vegetable oil with potassium methylate plays an important role (Ehsan and Tofajjal 2015; Baskar and Aiswarya, 2016). The quality of mixing affects the quality of diesel biofuel and its output. Since potassium methylate and oil form a two-phase medium, the formation of an emulsion with an increased contact area of the reagents is necessary for the intensification of the reaction, which is achieved by constant mixing (Qiu et al., 2010; Wulandani et al., 2015). In addition, irrational mixing modes can lead to a slowdown in the transesterification reaction (Qiu et al., 2010).

At this stage of the development of diesel biofuel production technologies the process of transesterification using alkaline catalysts has become widespread (Ehsan and Tofajjal, 2015). The results of the research indicate that the methanolysis method with the use for alkaline catalysts has the best effect if the temperature of the process is between 20°C and 70°C (Ehsan and Tofajjal, 2015). As a rule, the transesterification process at a temperature of about 40°C lasts up to 40 minutes. The ratio of methyl alcohol to oil is recommended from 6 to 1 in moles, and the catalyst content is up to 1% of the emulsion volume (Golub et al., 2015; Baskar and Aiswarya, 2016). It was also found that the quality of the methanolysis reaction during the diesel biofuel production is influenced by the hydrodynamic conditions of mixing (Ehsan and Tofajjal, 2015; Golub et al., 2018). There are theoretical studies aimed at determining the efficiency of mixing with the creation of turbulent regime in the emulsion jet. These studies allowed tosubstantiate the design parameters of a hydrodynamic plant for diesel biofuel production (Golub et al., 2017c).



1, 3, 9, 16. Hoppers for oilseeds, oilcake and grain components 2. Spring conveyor 4. Grain cleaning complex 5, 8. Screw conveyors 6, 7. Screw press-extruders of cold and hot pressing 10. Equipment for the production of diesel biofuels 11, 15, 19, 20. Capacities for storage of diesel biofuel, feed additives, oil for food and grain waste 12. Microadditives mixer 13, 14. Vertical-screw mixer of additives and mixed feed 17, 21. Oil decanter 18. Crystallizer 22. Mixer 23. Tractor

Figure 1 Technological scheme of two-stage expression of vegetable oil and diesel biofuel production (Golub et al., 2017a)

In the direction of transesterification process technical support, more research has been carried out in the direction of the development of reactors with mechanical mixers (Drahniev, 2010). The disadvantages of this mixing method include the formation of places of emulsion stagnation and significant specific energy consumption (Drahniev and Kukharets, 2010; Brásioa et al., 2011). A method for diesel biofuel production using the method of hydraulic mixing with the use of fixed nozzles is also known (Sungwornpatansakul et al., 2013; Golub et al., 2018), as well as with the use of reactors of conventional (Poppea et al., 2015) and rotating (Xua et al., 2017) types. The disadvantage of such reactors is low performance. Under the condition of low efficiency of mixing components for diesel biofuel production, the transesterification process does not fully take place. Therefore, in order to improve the quality of the process they are used additional operations of washing (Alamsyah and Loebis, 2014) and cleaning (Atadashi, 2015), which adversely affects the cost of fuel. Although it should also be noted that the properties of diesel biofuels depend not only on the technological process of its production, but also on the type of the used vegetable oil (Balkovskiy, 2011) and catalyst.

When searching for methods to improve the mixing process, the use of hydro-mechanical mixing should not be excluded. This process occurs during the departure of the mixture of vegetable oil and potassium methylate from the nozzles. Due to the departure of the mixture, a reactive force is formed, which causes the rotational movement of the mixer with the blades, which leads to double mixing of the emulsion components.

However, there are not enough studies describing the process of diesel biofuel production using hydro-mechanical mixing, which does not allow implementing the process of diesel biofuel production with sufficient efficiency. Therefore, the determination of the optimal design and technological parameters of the hydro-mechanical mixer for diesel biofuel production will improve the quality and efficiency of the process of vegetable oil. And the determination of the energy indicators of the process of vegetable oil transesterification will positively affect the cost of diesel biofuel production.

The aim of the work is to increase the efficiency of diesel biofuel production on the basis of improving the process of hydro-mechanical mixing.

2 Materials and methods

As a laboratory equipment for the diesel biofuels production with using the mechanical mixing the thermal water bath and the mechanical mixer EUROSTAR IKA was used (Figure 2).

(a) Thermal water bath (b) Mechanical mixer

Figure 2 The general view of the equipment for the diesel biofuels production in laboratory conditions with using the mechanical mixing

The general view of the pilot sample of the hydro-mechanical mixer for the diesel biofuel production is shown in Figure 3.

The studies were conducted using the D-optimal Box-Benghken plan. The names, levels and intervals of variation of factors during the studies are given in the Tables 2, 3 and 4.

Figure 3 Pilot sample of the hydro-mechanical mixer for the diesel biofuel production

Table 2 Intervals of values and variation levels of factors in determining the specific energy consumption of the process of diesel biofuel production with using of the laboratory mechanical mixer

Name of the input factors	Factor levels			Variation intervals
	–1	0	+1	
Mixture temperature, °C	5	25	45	20
Mixing time, min.	10	30	50	20
The frequency of mixer rotation, rpm	80	115	150	35

Table 3 Intervals of values, and variation levels of the factors while determining the frequency of hydro-mechanical mixer rotation

Name of the input factors	Factor levels			Factor levels
	–1	0	+1	
Nozzle diameter, mm	1.5	2.0	2.5	0.5
The frequency of the pump shaft rotation, rpm	700	1050	1400	350
The tilt angle of the blades, deg.	30	60	90	30

Table 4 Intervals of values and levels of variation of factors in determining the specific energy consumption of the process of diesel biofuel production with using of the hydro-mechanical mixer

Name of the input factors	Factor levels			Variation intervals
	–1	0	+1	
Nozzle diameter, mm	1.5	2.0	2.5	0.5
The frequency of the pump shaft rotation, rpm	700	1050	1400	350
Mixing time, min.	10	30	50	20

Assessment of the heterogeneity of variance of the experimental data was evaluated by Cochran criterion, the significance of the coefficients of the regression equations was tested according to Student's criterion and the adequacy of the obtained regression equations was evaluated by the Fisher criterion.

Determination of kinematic viscosity of biodiesel was carried out using and fluidmeter and the flash point temperature of diesel biofuel was determined in a closed firepot. These devices are shown in Figure 4.

(a) Fluidmeters (b) The device for determining the flash point temperature in the closed firepot

Figure 4 The general view of the devices for determination diesel biofuel quality parameters

Rapeseed oil and potassium methylate were used for the experiments.

3 Results and discussion

3.1 Results of the study of the specific energy consumption of the mechanical mixer

The results of measuring made it possible to determine the specific energy consumption of the process of diesel biofuel production with using of the laboratory mechanical mixer the values of which are shown in Table 5. The Cochran criterion amounted to $G=0.067$ and was less than its table value $G_T=0.335$ at a confidence level of 95%. This indicates the heterogeneity of variance of the experimental data.

Table 5 The value of the input factors and the output value – of the specific energy consumption of the process of diesel biofuel production with using of the laboratory mechanical mixer

Input factors:			Output value – the specific energy consumption of the mechanical mixer, kWh m^{-3}
Mixture temperature, °C	Mixing time, min.	Frequency of mixer rotation, rpm	
45	30	150	28.83
5	30	80	4.05
45	30	80	27.53
5	30	150	6.08
45	50	115	35.22
5	10	115	1.8
45	10	115	23.15
5	50	115	9.01
25	50	150	17.85
25	10	80	8.28
25	10	150	8.95
25	50	80	14.4
25	30	115	12.7
25	30	115	12.56
25	30	115	12.43

The regression equation to determine the specific energy consumption of the process of diesel biofuel production with using of the laboratory mechanical mixer is:

$$S_E = -3.7120 - 0.0368T + 0.0842n - 0.0119\tau + 0.0112T^2 - 0.0004n^2 + 0.0006\tau^2 - 0.0003Tn + 0.0030T\tau + 0.0010n\tau \quad (1)$$

where, S_E: the specific energy consumption of the mechanical mixer, kWh m^{-3}; T: the temperature of the mixture, °C; n: the frequency of rotation of the mixer, rpm; τ: mixing time, min.

The Fisher criterion at a confidence level of 95%, amounted to F=2.52 and was less than its table value F_T= of 2.53, indicating the adequacy of the obtained regression equation.

As a result of the analysis of the obtained equation, it was found that the specific energy consumption of the diesel biofuel is not significantly affected by the rotation frequency of the mechanical mixer (Figure 5). This is due to the fact that the increase in the speed does not lead to significant costs of electric energy.

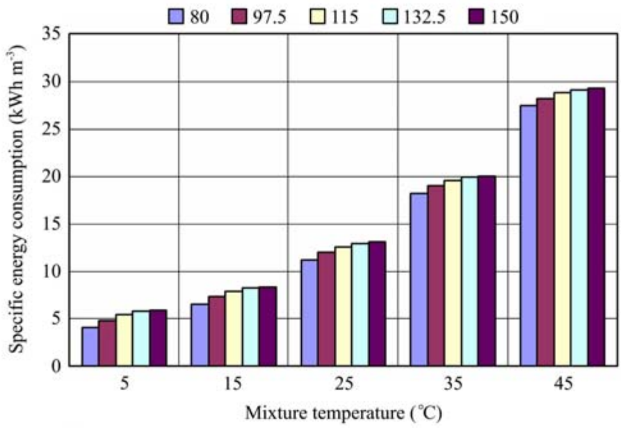


Figure 5 Dependence of the specific energy consumption of the transesterification process on the process temperature and the speed of the mechanical mixer rotation

An increase in the energy intensity of the mixing process is observed with the growth of the temperature of the esterification process (Figure 6) and mixing time (Figure 7). This is due to the need to use electric energy for heating and maintaining the temperature of the process of transesterification.

The minimum specific energy consumption of the process of production of diesel biofuels using a mechanical mixer was in the range of 2 to 7 kWh m^{-3} at a speed of the mixer shaft rotation of 80 rpm, mixing time

10 minutes and the temperature of the process of transesterification –5°C. The maximum specific energy consumption of the process of production of diesel biofuels was in the range of 30 to 35 kWh m^{-3} at a speed of the mixer shaft rotation of 150 rpm, mixing time 50 minutes and the temperature of the process of transesterification –45°C.

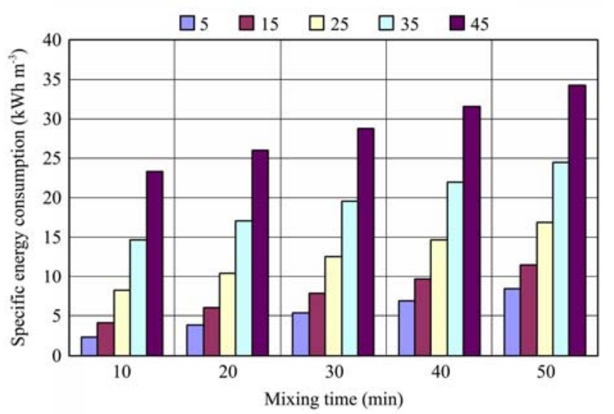


Figure 6 Dependence of the specific energy consumption of the transesterification process on the mixing time and the temperature of the process

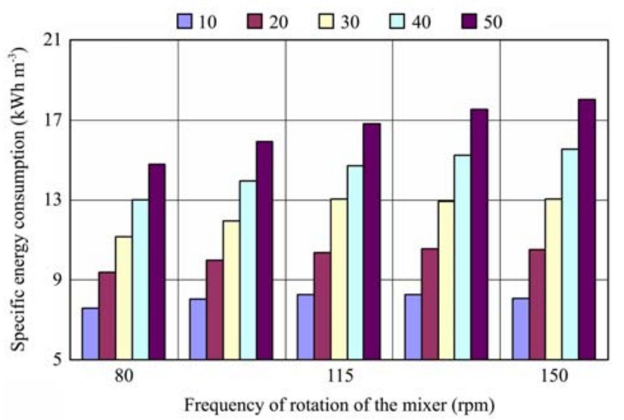


Figure 7 The dependence of the specific energy consumption of the transesterification process on the speed of the mechanical mixer and mixing time

3.2 The results of the study of the speed of the hydro-mechanical mixer rotation

The results of measuring made it possible to determine the frequency of hydro-mechanical mixer rotation the values of which are shown in Table 6. The Cochran criterion amounted to G=0.07 and was less than its table value $G_T = 0.335$ at a confidence level of 95%. This indicates the heterogeneity of variance of the experimental data.

Experimental studies have allowed forming a mathematical model to determine the speed of the hydro-mechanical mixer rotation:

$$n_H = 31.2125 - 37.0389d + 0.0763n_D - 0.3432\alpha + 7.0722d^2 + 0.002\alpha^2 - 0.0079dn_D \quad (2)$$

where, n_H: the frequency of rotation of the hydro-mechanical mixer, rpm; d: nozzle diameter, mm; n_D: pump shaft rotation frequency, rpm; α: tilt angle of blades, deg.

Table 6 The value of the input factors and the output value – of the frequency of hydro-mechanical mixer rotation

Input factors:			Output value – the frequency of hydro-mechanical mixer rotation, rpm
Nozzle diameter, mm	Frequency of the pump shaft rotation, rpm	Tilt angle of the blades, deg.	
2.5	1400	60	26
1.5	700	60	17.5
2.5	700	60	3
1.5	1400	60	46
2.5	1050	90	16
1.5	1050	30	38.5
2.5	1050	30	20
1.5	1050	90	31
2	1400	90	31
2	700	30	12.7
2	1400	30	40
2	700	90	9
2	1050	60	23
2	1050	60	22.8
2	1050	60	23

The Fisher criterion at a confidence level of 95%, amounted to F=2.38 and was less than its table value F_T= of 2.53, indicating the adequacy of the obtained regression equation.

As a result of the analysis of the obtained equation, it was found that reducing the diameter of the nozzles leads to an increase in the number of rotations of the hydro-mechanical mixer (Figure 8). This phenomenon can be explained by the fact that when reducing the diameter of the nozzle the velocity of the fluid increases, which leads to an increase of the reactive force that compels to increasing the rotation frequency of the shaft of the hydro-mechanical mixer.

Studies on determining the effect of the tilt angle of the blades on the speed of the hydro-mechanical mixer showed that with the increase in the tilt angle of the blades the speed of the mixer decreases (Figure 9). This phenomenon is explained by the fact that when the tilt angle of the blades increases, their drag increases.

Studies have also shown that the rotation frequency of the blades of the hydro-mechanical mixer increases with the growth of the pump shaft rotation frequency (Figure 10).

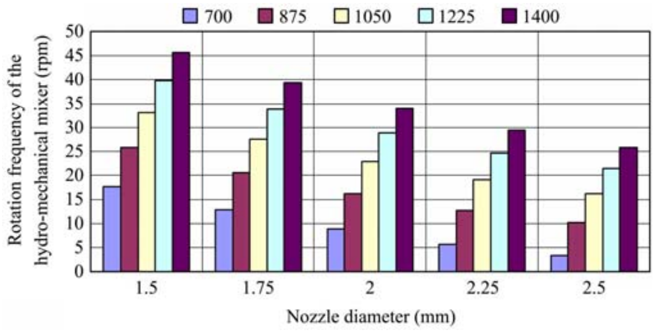


Figure 8 Dependence of the rotation frequency of the hydro-mechanical mixer on the diameter of the nozzles and the rotation frequency of the pump shaft

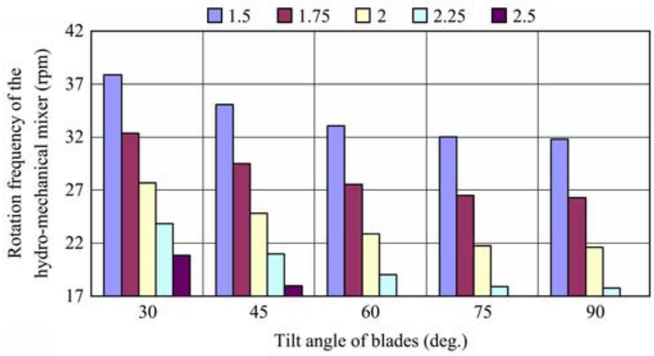


Figure 9 The dependence of the rotation frequency of the hydro-mechanical mixer on the diameter of the nozzles and the tilt angle of the blades

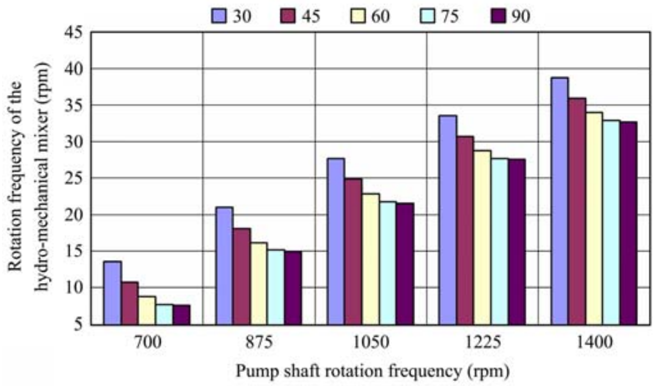


Figure 10 The dependence of the rotation frequency of the hydro-mechanical mixer on the tilt angle of the blades and the rotation frequency of the pump shaft

Experimental studies have shown that the maximum rotation frequency of the hydro-mechanical mixer was in the range of 39 to 45 rpm at a speed of 1400 rpm of the pump shaft, the diameter of the nozzles ranged from 1.5 to 2 mm and the tilt angle of the blades 30 deg. The minimum rotation frequency of the hydro-mechanical mixer was in the range of 2 to 5 rpm at a speed of 700 rpm of the pump shaft, the diameter of the nozzles ranged 2.5 mm and the tilt angle of the blades 90 deg.

3.3 Results of the study of specific energy consumption of the hydro-mechanical mixer

The results of measuring made it possible to determine the specific energy consumption of the hydro-mechanical mixer the values of which are shown in Table 7. The Cochran criterion amounted to G=0.08 and was less than its table value $G_T = 0.335$ at a confidence level of 95%. This indicates the heterogeneity of variance of the experimental data.

Table 7 The value of the input factors and the output value – of the specific energy consumption of hydro-mechanical mixer

Input factors:			Output value – the specific energy consumption of the hydro-mechanical mixer, kWh m^{-3}
Nozzle diameter, mm	Frequency of the pump shaft rotation, rpm	Mixing time, min.	
2.5	1400	30	0.934
1.5	700	30	1.219
2.5	700	30	1.012
1.5	1400	30	2.422
2.5	1050	50	1.390
1.5	1050	50	1.616
2.5	1050	10	1.440
1.5	1050	50	2.561
2.0	1400	50	2.872
2.0	700	10	0.834
2.0	1400	10	1.125
2.0	700	50	1.080
2.0	1050	30	1.204
2.0	1050	30	1.226
2.0	1050	30	1.046

Experimental studies have allowed forming a mathematical model to determine the specific energy consumption during diesel biofuel production with the help of a hydro-mechanical mixer on the diameter of the nozzles, the rotation frequency of the pump shaft and the mixing time is as follows:

$$S_E = 0.9121 - 0.7601d + 0.0011n_D + 0.018\tau \quad (3)$$

where, S_E: specific energy consumption of the hydro-mechanical mixer, kWh m^{-3}.

The Fisher criterion at a confidence level of 95%, amounted to F=2.49 and was less than its table value F_T= of 2.53, indicating the adequacy of the obtained regression equation.

As a result of the analysis of the obtained equation, it was found that the reduction in the diameter of the nozzles of the hydro-mechanical mixer leads to an increase in the specific energy consumption in the process of diesel biofuel production (Figure 11). The increase in the specific energy consumption of the process is due to an increase in the power consumption of the electric motor, and this, in turn, is the result of an increase in the pump pressure.

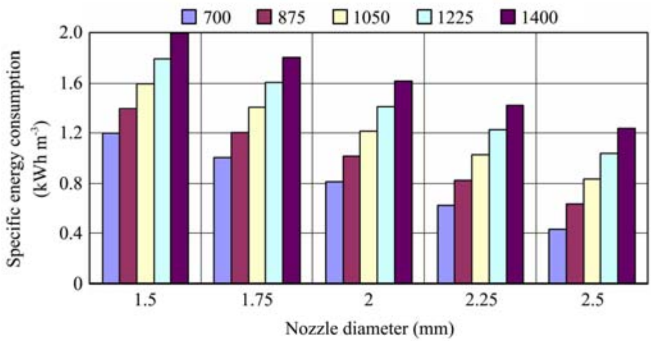


Figure 11 The dependence of the specific energy consumption of the hydro-mechanical mixer on the diameter of the nozzles and the rotation frequency of the pump shaft

Studies have shown (Figure 12) that there is a direct relationship between the increase in mixing time and specific energy consumption due to the increase in electricity costs.

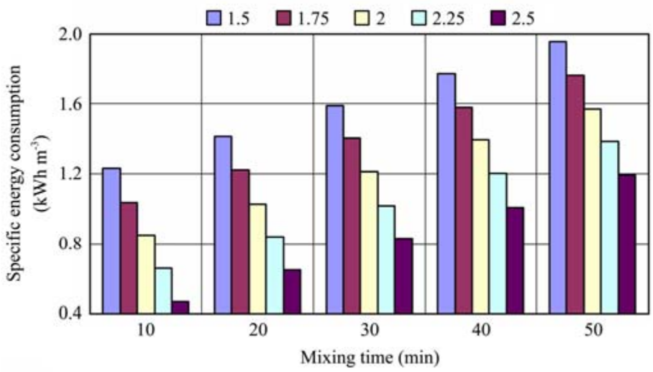


Figure 12 The dependence of the specific energy consumption of the hydro-mechanical mixer on the diameter of the nozzles and mixing time

As the pump speed increases, the specific energy consumption of the hydro-mechanical mixer increases due to an increase in the pump capacity (Figure 13).

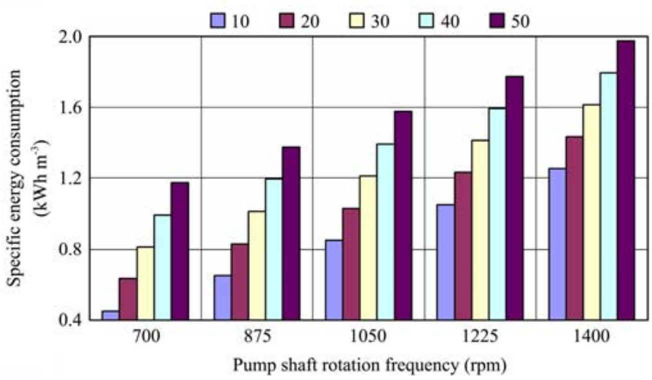


Figure 13 The dependence of the specific energy consumption of the hydro-mechanical mixer on the rotation frequency of the pump shaft and the mixing time

Thus, it was found that the minimum values of the specific energy consumption while diesel biofuel production by means of a hydro-mechanical mixer were in the range of 0.43 to 0.47 kWh m^{-3} at the pump shaft rotation frequency of 700 rpm, mixing time of 10 min and nozzle diameter of 2.5 mm. The maximum specific energy consumption of the process of production of diesel biofuels were in the range of 1.96 to 1.99 kWh m^{-3} at the pump shaft rotation frequency of 1400 rpm, mixing time of 50 min and nozzle diameter of 1.5 mm.

3.4 Results of the study of diesel biofuel quality parameters

The results of research on the properties of the diesel biofuel obtained are shown in Figure 14 and 15.

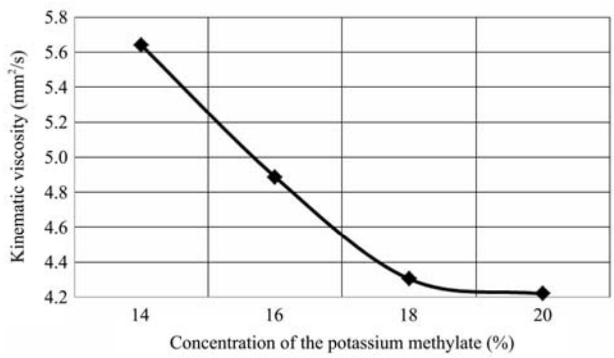


Figure 14 The dependence of the kinematic viscosity of the diesel biofuel obtained on the concentration of the potassium methylate

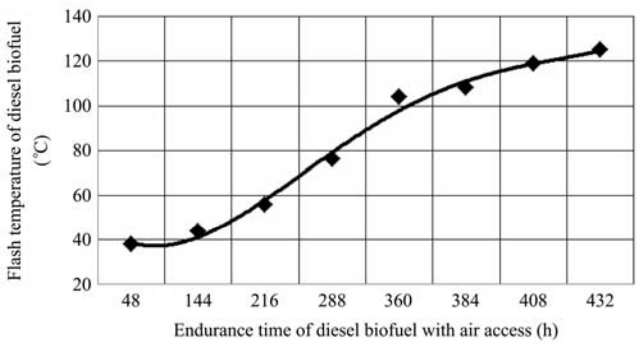


Figure 15 The dependence of the the flash temperature of diesel biofuel on the endurance time of diesel biofuel with air access

The analysis of the influence of potassium methylate on the kinematic viscosity of diesel biofuel showed that at least 16 mL of potassium methylate per 100 mL of vegetable oil should be added to obtain the normative values of the kinematic viscosity of diesel biofuel. The smallest kinematic viscosity of 4.21 mm^2/s was achieved at a concentration of potassium methylate 20 mL per 100 mL of vegetable oil.

The flash temperature of diesel biofuel increases with the increase the endurance time of diesel biofuel through the allocation of excess methyl alcohol. The normative flash temperature of diesel biofuel was achieved at 400 hours of endurance time with free access to air and was 120°C.

4 Results and discussion

Vegetable oil export from Ukraine is on the first place in the world. Large-scale production of vegetable oil causes a significant oilseeds production. However the export of vegetable oil makes it impossible to produce diesel biofuel in large volumes. Potential of the biodiesel production in Ukraine using grain wastes of rape, soybean and sunflower can be up to 100 thousand tons. Such production volumes of biodiesel in terms of agrarian production will have a positive impact on Ukraine's energy independence and reduce greenhouse gas emissions into the atmosphere.

The using of mechanical mixers has become the most widespread in diesel biofuel technologies. At the same time, there are technical solutions in which the hydro-mechanical principle of mixing is applied. Hydro-mechanical mixing to the greatest extent allows providing a combination of two stages of mixing, namely, intensive and smooth. In such conditions, the process of transesterification proceeds with the maximum yield of diesel biofuel from the vegetable oil.

The conducted researches allowed performing comparison of the indices of specific power consumption of diesel biofuel production process with use of mechanical and hydro-mechanical mixing. Studies have shown that when using a mechanical mixer, the specific energy consumption was in the range of 2 to 35 kWh m^{-3} at a speed of the mixer shaft rotation in the range of 80 to 150 rpm, changing the mixing time in the range of 10 to 50 minutes and changing the temperature of the process of transesterification in the range of 5°C to 45°C. When using a hydro-mechanical mixer, the specific energy consumption of the diesel biofuel production was in the range of 0.43 to 1.99 kWh m^{-3} at a changing the pump shaft rotation frequency in the range of 700 to 1400 rpm, changing the mixing time in the range of 10 to 50 minutes and changing the nozzle diameter in the range of 1.5 to 2.5 mm. In this case, the temperature of transesterification process was at a level from 8°C to 10°C and the need for its increase disappears. The results of these studies show the advantage of the hydro-mechanical method of mixing over mechanical and allow a positive impact on the economic performance of diesel biofuel production.

The minimum specific energy consumption was provided by the following values of the parameters of the hydro-mechanical mixer, namely: the pump speed – 700 rpm; the nozzle diameter – 2.5 mm; the tilt angle of the blades – 30; mixing time – 50 min; the process temperature – not less than 5°C. Further reduction of the specific energy consumption due to reduction of the pump speed and increasing of the nozzle diameter is impossible, as this may lead to the termination of the rotation of the hydro-mechanical mixer. At the same time, the quantitative yield of diesel biofuel was 98.8%, the average kinematic viscosity of diesel biofuel was 4.99 $mm^2 s^{-2}$, the average flash point of diesel biofuel was 135.2°C, the rotation frequency of the hydro-mechanical mixer was 3.39 rpm, the power consumption was 77.9 W, the specific energy consumption of the equipment for diesel biofuel production was 1.42 kWh m^{-3}.

The analysis of the influence of potassium methylate on the kinematic viscosity of diesel biofuel showed that at least 16 mL of potassium methylate per 100 mL of vegetable oil should be added to obtain the normative values of the kinematic viscosity of diesel biofuel. The flash temperature of diesel biofuel increases with the increase the endurance time of diesel biofuel through the allocation of excess methyl alcohol. The normative flash temperature of diesel biofuel was achieved at 400 hours of endurance time with free access to air and was 120°C.

The determination of the design and technological parameters of the hydro-mechanical mixer for diesel biofuel production in agricultural production based on the results of experimental studies allowed developing p a technique for the engineering calculation of the hydro-mechanical mixer. The results of production tests proved the efficiency of the equipment.

The obtained results allow checking the design solutions in the development of new types of mixers, determining the effect of oil quality indices on the performance of the plant for diesel biofuel production.

Further experimental and theoretical studies are planned in the direction of further improvement of the mixing system for diesel biofuel production. The results of these studies will be the basis for further optimization of parameters of diesel biofuel production with using a hydro-mechanical mixer. As well as establishing the possibility of diesel biofuel production in the context of energy independence of agricultural producers.

5 Conclusions

1. Experimental studies to determine the specific energy consumption of diesel biofuel production using mechanical mixing showed that the specific energy consumption was in the range of 2 to 35 kWh m^{-3} at a speed of the mixer shaft rotation in the range of 80 to 150 rpm, changing the mixing time in the range of 10 to 50 minutes and changing the temperature of the process of transesterification in the range of 5°C to 45°C.

2. Experimental studies have shown that the speed of the hydro-mechanical mixer depends on the diameter of the nozzles. The values of the speed of the hydro-mechanical mixer are in the range from 2 to 45 rpm at a changing the pump shaft rotation frequency in the range of 700 to 1400 rpm, changing the nozzle diameter in the range of 1.5 to 2.5 mm and the tilt angle of the blades in the range of 30 to 90 deg.

3. The results of a multi-factor experimental study showed that the minimum values of the specific energy consumption of diesel biofuel production with the use of a hydro-mechanical mixer was in the range of 0.43 to 1.99 kWh m^{-3} at a changing the pump shaft rotation frequency in the range of 700 to 1400 rpm, changing the mixing time in the range of 10 to 50 minutes and changing the nozzle diameter in the range of 1.5 to 2.5 mm.

4. To obtain the normative values of the kinematic viscosity of diesel biofuel should be added least 16 mL of potassium methylate per 100 mL of vegetable oil, and the normative flash temperature of diesel biofuel is achieved at 400 hours of endurance time with free access to air.

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