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THE DETERMINATION OF PARAMETERS OF A REACTOR-MIXER WITH A DISK INJECTOR

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To improve efficiency of mixing and energy consumption of biodiesel production it is suggested to use a reactor-mixer equipped with a disk injector. It creates circulation mixing by multiple liquid pumping through the closed loop. A disk injector is adjusted in the upper part of a mixer with a possibility of movement along an axis of a reactor-mixer. A disk injector makes it possible to mix the emulsion components within the layer on fixed height. It helps to reduce energy consumption for mixing. Turbulence, created when emulsion moves through a disk injector, provides necessary efficiency of mixing. References 10, tables 2, figures 6.

Keywords: diesel biofuel, transesterification, hydraulic pump, Reinold's number, hydraulic mixing, energy efficiency.

ВИЗНАЧЕННЯ ПАРАМЕТРІВ РЕАКТОРА-ЗМІШУВАЧА ІЗ ДИСКОВОЮ ФОРСУНКОЮ

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Для підвищення ефективності перемішування та споживання енергії при отриманні дизельного біопалива пропонується використовувати реактор-змішувач, обладнаний дисковою форсункою. Реактор-змішувач забезпечує циркуляційне перемішування, що здійснюється багатократним перекачуванням рідини по замкненому контуру. Дискову форсунку встановлено у верхній частині змішувача із можливістю її руху вздовж осі реактора-змішувача. Вона дозволяє виконувати змішування компонентів емульсії у прошарку фіксованої висоти. Це дозволяє зменшити витрату енергії на перемішування. Турбулентність, створювана під час проходження емульсії крізь дискову форсунку, забезпечує необхідну ефективність змішування емульсії. Бібл. 10, табл. 2, рис. 6.

Ключові слова: дизельне біопаливо, переестерифікація, гідронасос, число Рейнольдса, гідравлічне перемішування, енергетична ефективність.



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List of symbols and abbreviations:

θ – the expansion angle for a symmetric stream, radian;
 Q_V – the hydraulic pump productivity, m³/s;
 Q_O, Q_F, Q_X – the emulsion consumption in proper injector splits, m³/s;
 V_V, V_O, V_F – the motion speed of emulsion in injector splits, m/s;
 d – a split between the injector disks (the thickness of an injector nozzle), m;
 h_0 – an initial thickness of a disk injector, m;
 h_X – the stream thickness in active cross sectional view, m;
 L_X – the length of an active part of a stream, m;
 D_F – a diameter of a disk injector, m;
 D_O – a diameter of a disk injector near the entry pipeline, m;
 d_V – the diameter of an inlet part of a disk injector, m;

A_F – an area of a cross section view of an injector on perimeter (at outlet), m²;
 A_O – an area of a cross section view of an injector near the entry pipeline, m²;
 A_V – an area of a cross section view of an intake pipeline, m²;
 R_g – a hydraulic radius of a stream in active cross section, m;
 R_e – Reynolds’ number;
 ν – a viscosity-density ratio, m²/s;
 η – a dynamic emulsion viscosity, Pa·s;
 ρ – an emulsion density, kg/m³;
 n_D – the frequency of pump rotation, per/min;
 h_F – the depth of dipping, m;
 v_X – the speed in active cross section view of a stream, m/s.

Introduction. The quality of the reaction of transesterification processing depends on hydrodynamic conditions [8] and requires a proper mixing intensity [3]. The most spread reactors for performing the process of transesterification are the ones which are equipped with mechanical mixers [9]. The mathematical model of the technological process of transesterification for the production of diesel biofuel has been developed on the basis of fuzzy logic [3, 4]. The technological process of transesterification of the vegetable oils in batch reactors has been modelled [3, 4]. But in the production of diesel biofuel there are some problems related to mixing of the emulsion components in the process of transesterification. They are: a significant duration of the process, a destruction of a required surface area of the reagents contact, a significant energy consumption [3].

It often happens that the fermentation reactors of ordinary and of rotation [7] types are used for the production of diesel biofuel, but they have low productivity. Because of insufficient efficiency of mixing, the process of transesterification is performed not completely, that is why additional operations on washing [10] and cleaning [1] are used which make the technological process of receiving diesel biofuel under the conditions of agrarian production more complicated.

In the research related to the application of membrane and tube [6] mixers, on the basis of cavitation it has been shown that the rate of transesterification process increases under condition of mixing small amounts of emulsion components. But such technologies of diesel biofuel production are characterized by high specific energy consumption.

Similar results related to the efficiency of a mixing process are achieved in reactors with nozzles application as well as with the emulsion circulation outside the closed tube [4]. Under the condition of hydraulic mixing the efficiency of transesterification process is maintained when there is a turbulent regime in the emulsion flow [2]. The use of machines with a hydraulic emulsion mixing and with circulation enables to run the processes of transesterification and setting-out in one container. But in the working process of such a reactor may form the areas of stagnation. The issue related to a safe removing of diesel biofuel received in the process of reaction

has not been solved either.

A carried out analysis allows us to make a conclusion that an existing and a perspective equipment for diesel biofuel production does not fully provide the efficiency of a technological process under the conditions of an agrarian producer. It is necessary to conduct a theoretical substantiation as well as experimental research of the parameters of the equipment for diesel biofuel production with an application of hydraulic mixing.

Task setting. The research goal is to increase the level of energy efficiency of diesel biofuel production by improving the construction of a hydraulic reactor-mixer.

To achieve the goal it is necessary: to improve the mathematic model of emulsion mixing in a reactor-mixer with an application of a disk injector; to determine the main parameters of a reactor-mixer and of a disk injector; to conduct an experimental testing of reactor-mixer's energy efficiency.

The presenting of main material. *The procedure of experimental research.* An experimental machine has been developed for conducting the research on the energy efficiency of a reactor-mixer. It included: a reactor-mixer for transesterification of vegetable oil, a hydropower station (Fig. 1) and measuring equipment. The measuring equipment consists of: the transformer of energy frequency Hitachi-3-G3JX-A4075-EF (Japan); the analyzer of the parameters of energy consumption DMK-30 (Italy); the tachometer UT-372 (China); the notebook Acer-I3 (China) [4, Fig. 2].

When carrying out an experiment an emulsion on the basis of rape oil in amount of 2000 l was pumped by means of hydropower station to the mixer for transesterification. The emulsion mixing was run under the temperature of 40 °C. The period of mixing was from 222 to 888 s (222 s – 1 multiple emulsion circulation, 444 s – 2 multiple, 666 s – 3 multiple and 888 s – 4 multiple).

An experiment on the plan of Boks-Benkin was carried out in order to determine the interconnection between the impact of a gap clearance between the disks of a nozzle (d), the frequency of pump rotation (n_D) and the depth of dipping (h_F) and the specific power of a pump (P).

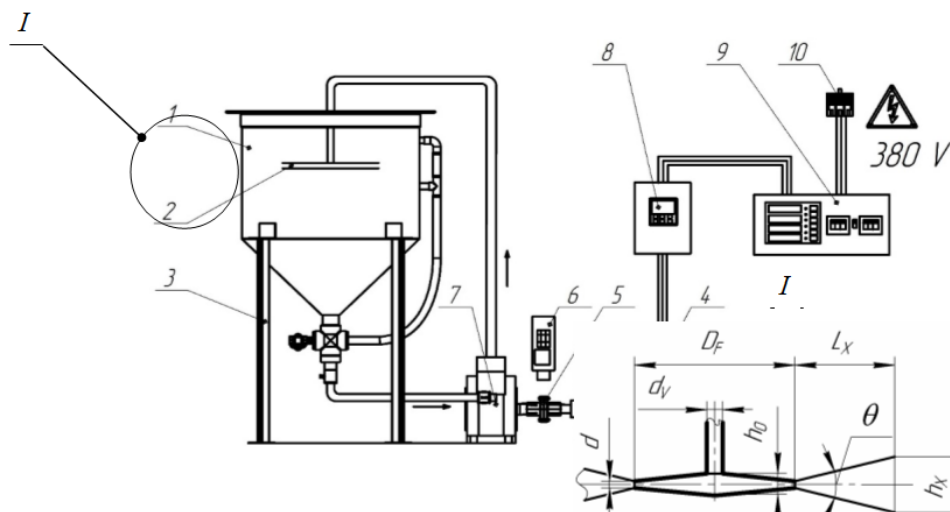


Fig. 1. The scheme of experimental circulation machine for diesel biofuel production:

- 1 – a circulatory reactor-mixer; 2 – a disk injector; 3 – a frame; 4 – electric generator; 5 – a joint; 6 – optical tachometer; 7 – gear-type pump; 8 – a transformer of energy frequency; 9 – an analyzer of energy consumption parameters; 10 – a source of power supply.

Рис. 1. Схема експериментальної циркуляційної установки для виробництва дизельного біопалива:

- 1 - циркуляційний реактор-змішувач; 2 - дисковий інжектор; 3 - рамка; 4 - електричний генератор; 5 - з'єднувач; 6 - оптичний тахометр; 7 - насос редукторного типу; 8 - трансформатор частоти енергії; 9 - аналізатор параметрів енергоспоживання; 10 - джерело живлення.

The intervals of the factors under investigation are given in Table 1.

Table 1. The intervals of the factors under investigation

Таблиця 1. Інтервали досліджуваних факторів

Name of a factor	Levels of a factor			Variety intervals
	-1	0	+1	
Depth of dipping, mm	0	50	100	50
Frequency of generator rotation, per /min	96	496	896	400
Gap clearance between disks of an injector, mm	2,2	4,4	6,6	2,2

The results of theoretical research of a reactor-mixer. Circulating mixing which is performed by frequent liquid repumping outside the closed circuit has been suggested for the process of transesterification of vegetable oils. A disk injector has been fixed in the upper part of a mixer [4, Fig. 4] that enables it to move along the axe of a reactor-mixer. When emulsion passes through a disk injector a turbulent flow is formed, it supports a proper emulsion mixing efficiency in a layer at a fixed height. Due to emulsion pumping from a lower part of a mixer an emulsion layer goes down, a mixing efficiency decreases, an intensive transesterification reaction starts.

An emulsion stream that flows out of a disk in-

jector (Fig. 1) gradually extends and due to viscosity action it draws in the liquid which is around the stream [5]. Under the continuous flow [5] the emulsion consumption in all injector splits as well as in streams is similar and it equals a hydropump productivity (Q_V) that is $Q_V=Q_O=Q_F=Q_X$. To avoid additional pressure losses, let's take the motion speed of emulsion in injector splits as constant one: $V_V=V_O=V_F$

Having written the areas of cross section views:

$$\begin{cases} A_F = \pi D_F d, \\ A_0 = \pi D_0 h_0, \\ A_V = \pi d_V^2 / 4. \end{cases} \quad (1)$$

We can determine the split between the injector's disks at outlet:

$$d = \frac{D_0 h_0}{D_F} = \frac{d_v^2}{4D_F}. \quad (2)$$

The stream thickness in active cross section view will be:

$$h_x = d + 2L_x \operatorname{tg} \frac{1}{2} \theta. \quad (3)$$

The speed in active cross section view of a stream can be determined according to [5], like with liquid flow through the vents and fixtures (injectors) on the formula:

$$v_x = \frac{Q_0}{\pi \left(\frac{1}{2} D_F + L_x \right) \left(h_x + 2L_x \operatorname{tg} \frac{1}{2} \theta \right)}. \quad (4)$$

Having taken R_g like for a quadrangular cross section view, we can determine Re_e , according to which we can determine L_x with a proper mixing intensity ($Re \geq 2320$) [5]:

$$R_G = \frac{\pi \left(\frac{1}{2} D_F + L_x \right) \left(d + 2L_x \operatorname{tg} \frac{1}{2} \theta \right)}{\pi (D_F + 2L_x) + \left(2d + 4L_x \operatorname{tg} \frac{1}{2} \theta \right)}, \quad (5)$$

$$Re = \frac{Q_v}{v \left(L_x \left(2 \operatorname{tg} \frac{1}{2} \theta + \pi \right) + d + \frac{\pi D_F}{2} \right)} \geq 2320, \quad (6)$$

$$Re = \frac{Q_v \rho}{\eta \left(L_x \left(2 \operatorname{tg} \frac{1}{2} \theta + \pi \right) + d + \frac{\pi D_F}{2} \right)} \geq 2320, \quad (7)$$

Using a formula (6):

$$L_x = \frac{1}{2 \operatorname{tg} \frac{1}{2} \theta + \pi} \left(\frac{Q_v \rho}{2320 \eta} - d - \frac{\pi D_F}{2} \right). \quad (8)$$

We can determine the value of an active length of emulsion stream as well as the dependence between Q_v and L_x (Fig. 2).

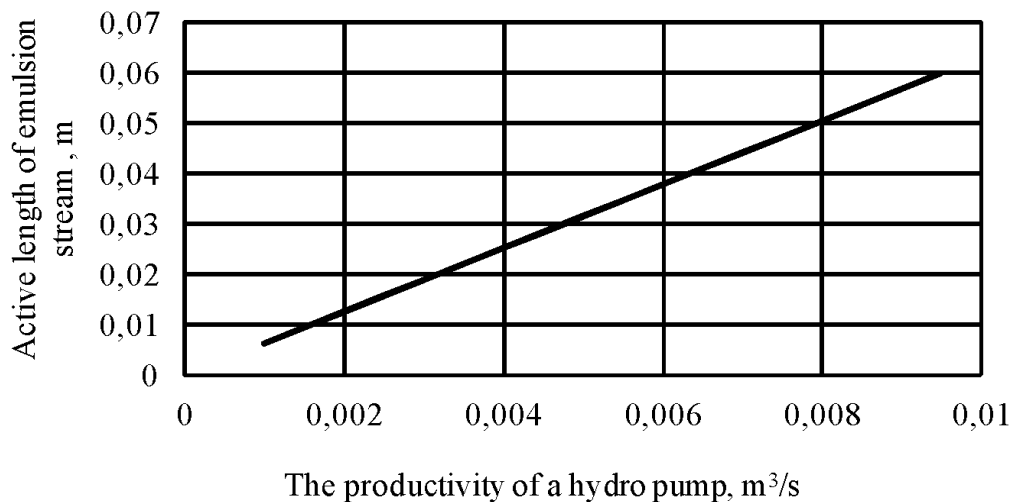


Fig. 2. The dependence of an active length of emulsion stream from a hydraulic pump productivity (the dynamic emulsion viscosity is 0,02 Pa·s).

Рис. 2. Залежність активної довжини струменя емульсії від продуктивності гідронасоса (динамічна в'язкість емульсії 0,02 Па·с).

The dependence between the dynamic viscosity of emulsion η and an active length of a stream L_x (Fig. 3) has been determined as well.

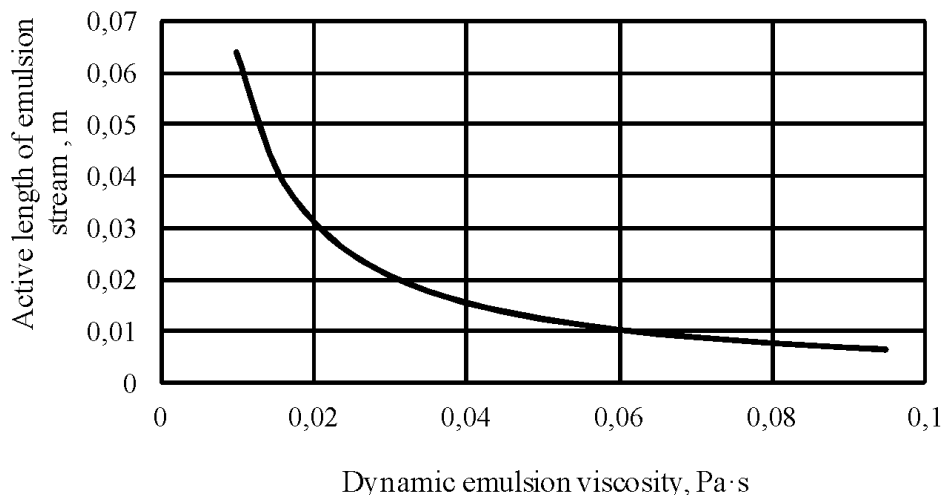


Fig. 3. The dependence of an active length of emulsion stream from dynamic viscosity of emulsion (hydraulic pump productivity is 0,005 m³/s).

Рис. 3. Залежність активної довжини струменя емульсії від динамічної в'язкості емульсії (продуктивність гідронасоса 0,005 м³/с).

Table 2. Sustainable Parameters of a Reactor-Mixer

Таблиця 2. Раціональні параметри реакторів-змішувачів

Parameter	Inner diameter of a reactor, m					
	0,8	1,2	1,4	2,2	3,0	3,2
Nominal volume, m³	0,4	1	2	10	50	63
Disk injector diameter, m	0,75	1,10	1,30	2,05	2,80	3,00
Thickness of an injector nozzle, mm	5	5	5	10	10	10
Height of mixing area, m [4, Fig. 2]	0,077	0,095	0,100	0,11	0,12	0,13
Height of a divider, m [4, Fig. 2]	0,95	1,10	1,60	3,00	7,65	8,45
Pump output, m³/s	0,006	0,008	0,009	0,011	0,012	0,014
Theoretical capacity of a pump, W	96	128	144	176	192	224
Period of a single-shot emulsion circulation, s	67	125	222	909	4167	4500

On the basis of compatible solving of the equations (3–8) the interdependence between the values of a mixer parameters and a disk injector has been determined. The main geometric size of a reactor-mixer (Table 2) has been received. The theoretical capacity of a hydraulic pump has been determined by multiplying pressure in an injector and emulsion expenses through the injector.

The pressure in a disk injector in all variants of D_z equals $P=16$ kPa. The parameters given in Table 2 enable us to use a geometrical form of a reactor-mixer most efficiently.

The Results of the Experimental Research of a Reactor-mixer.

$$P = 158.1794 + 0.8904h_F - 0.0123 n_D + 5.5220d + 0.0025n_D^2 - 0.0366 n_D d \quad (9)$$

The quotation analysis shows that if the gap clearance increases, the utilized capacity decreases due to the reduction of energy consumption by electrical generator which rotates hydraulic pump shaft. It can be explained by reducing resistance losses when emulsion passes through the injector.

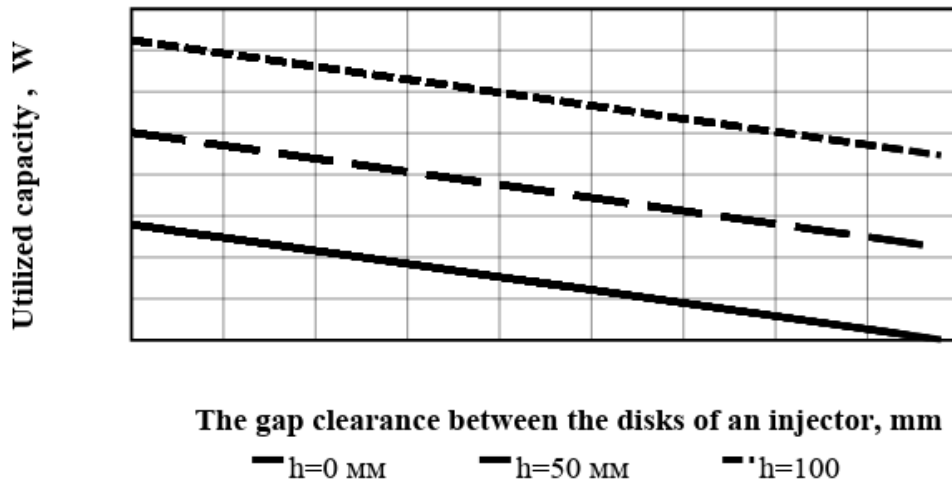


Fig. 4. The dependence of utilized capacity of a hydraulic pump from the depth of dipping as well as from the gap clearance between the disks.

Рис. 4. Залежність споживаної потужності гідравлічного насосу від зазору між дисками та глибини занурення.

When the injector’s depth of dipping increases the utilized capacity of a pump increases as well (Fig. 5). It can be explained by higher rate of energy consumption of an electric generator which rotates the pump shaft caused by the increase of a hydrostatic pressure.

It is also determined (Table 3) that when the frequency of a shaft rotation of a pump increases, the utilized capacity increases as well. It can be explained by an increase in energy consumption of a generator owing to the increase of pump’s productivity.

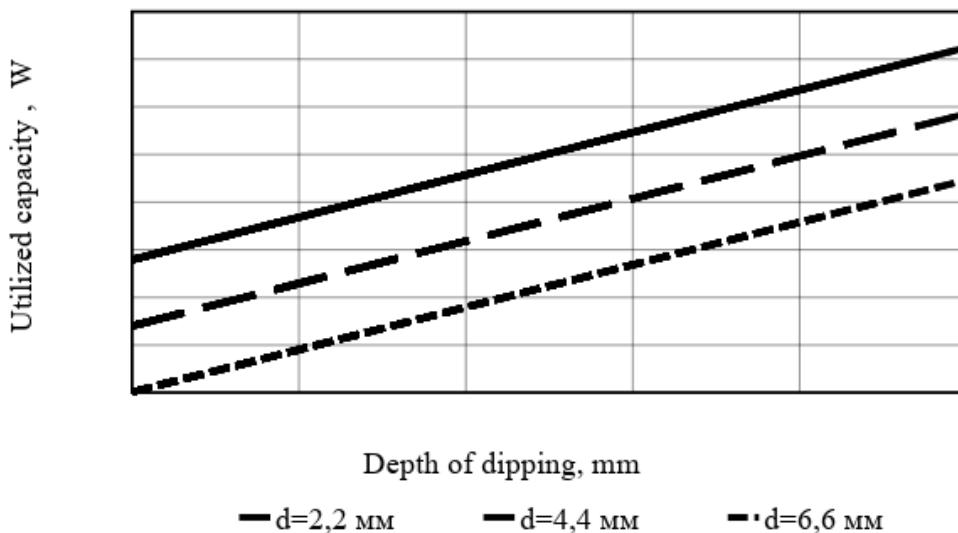


Fig. 5. The dependence of utilized capacity of a hydraulic pump from the depth of dipping as well as from the gap clearance between the disks.

Рис. 5. Залежність споживаної потужності гідравлічного насосу від глибини занурення та зазору між дисками.

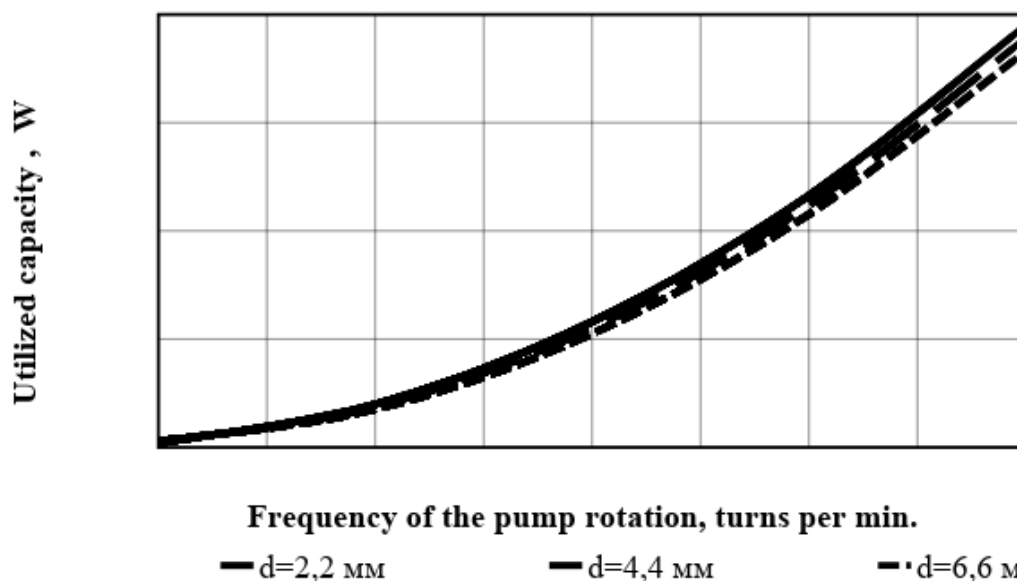


Fig. 6. The dependence of utilized capacity of a hydraulic pump from the rotation frequency of its shaft as well as from the gap clearance between the disks.

Рис. 6. Залежність споживаної потужності гідронасоса від частоти обертання його валу та зазору між дисками.

Minimal utilized capacity (230 W) is achieved when the gap setting between the disks of an injector equals 6.6 mm, the frequency of a pump rotation equals 96 turns per min and when there is zero depth of dipping. When the frequency of pump rotation increases up to 896 turns per min, the gap clearance between the disks reduces up to 2.2 mm and the dipping depth is maximal, the utilized capacity is maximal and it equals 2159 Wt. Under practical (Table 1) gap clearance indexes of 5 mm between the disks of an injector, and a maximal depth of dipping 50 mm, (which equals half of the thickness of emulsion stream near the walls of a reactor-mixer) as well as under the nominal frequency of 200 turns/min of a hydraulic pump shaft (PG-100, Ukraine), the utilized capacity will equal 292 W. The experimentally determined utilized capacity (292 W) is higher than theoretical capacity (144 W) due to additional capacity expenses on emulsion circulation. The specific capacity on emulsion mixing and circulating for a reactor-mixer 2 m³ in volume will equal 146 W/m³.

Conclusions. 1. On the basis of the equation of flow continuity and taking Reynolds' number into consideration, an active length of emulsion stream (with a proper mixing intensity) as well as the main

geometric parameters of a reactor-mixer for the production of diesel biofuel have been determined.

2. The main parameters of a reactor-mixer have been determined as standard ones for the units of equipment with a cone bottom in chemical industry. For the agrarian production the more suitable is a reactor-mixer 2 m³ in volume, with a disk injector 1.10 m in diameter, with injector nozzle 5 mm thick, internal diameter 1.4 m and 1.6 m high.

3. Under practical indexes of a 5 mm gap clearance between the disks of an injector, nominal 200 turns per min. frequency of a pump rotation, 50 mm depth of a disk injector dipping which equals half of emulsion stream thickness near the reactor-mixer walls, the utilized capacity will be 292 W. Specific capacity on emulsion mixing and circulating for the reactor-mixer 2 m³ in volume will be 146 W/m³.

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ОПРЕДЕЛЕНИЕ ПАРАМЕТРОВ РЕАКТОРА-СМЕСИТЕЛЯ С ДИСКОВОЙ ФОРСУНКОЙ

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Для повышения эффективности перемешивания и потребления энергии при получении дизельного биотоплива предлагается использовать реактор-смеситель, оборудованный дисковой форсункой. Реактор-смеситель обеспечивает циркуляционное перемешивание, осуществляемое многократным перекачиванием жидкости по замкнутому контуру. Дисковую форсунку установлено в верхней части смесителя с возможностью ее движения вдоль оси реактора-смесителя. Она позволяет выполнять смешивания компонентов эмульсии в прослойке фиксированной высоты. Это позволяет уменьшить расход энергии на перемешивание. Турбулентность, создаваемая при прохождении эмульсии через дисковую форсунку, обеспечивает необходимую эффективность смешивания эмульсии. Библ. 10, табл. 2, рис. 6.

Ключевые слова: дизельное биотопливо, переэтерифика-

ция, гидронасос, число Рейнольдса, гидравлическое перемешивание, энергетическая эффективность.

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SYNOPSIS

Diesel biofuel is mainly received in the process of transesterification, due to the interaction of vegetal oil and methyl spirit under catalysts presence. Methyl spirit, catalyst and oil create a multiphase medium in which the reaction process is going slower. To speed up the transesterification reaction it is necessary to create the emulsion with an increased area of reagents contact, which can be done by means of constant mixing. An efficient mixing determines the completeness of the process

of transesterification and effects both qualitative and quantitative indexes of diesel biofuel output.

To achieve the above mentioned it was proposed an improved mathematical model for emulsion mixing process in reactor-mixer with disk injector and main parameters for reactor-mixer and disk injector were received. This disk injector can be used for removing the received diesel biofuel from a reactor-mixer after the technological operations of transesterification and sedimentation. A disk injector enables to pump the received biofuel beginning from the upper part of a reactor-mixer that prevents glycerine from getting into the biofuel. The application of disk injectors in mixers makes it possible to produce diesel biofuel on a simplified technology as well as to remove it fully from the mixer under the conditions of farming. In a process of a four-time emulsion pumping on a closed circuit and after a proper sedimentation we received diesel biofuel with a coefficient of kinematic viscosity $4.25 \text{ mm}^2/\text{sec}$ and a flash temperature $125 \text{ }^\circ\text{C}$. A lower calorific value of a received diesel biofuel was 36.96 MJ/kg . The output of diesel biofuel was 85.6% from a utilized rape oil.

РЕФЕРАТ

Дизельне біопаливо, в основному, отримують в процесі переестерифікації, завдяки взаємодії рослинної олії та метилового спирту у присутності каталізаторів. Метилловий спирт, каталізатор та олія утворюють багатофазне середовище, в якому проходження реакції сповільнене. Для при-

швидшення проходження реакції переестерифікації необхідне утворення емульсії зі збільшеною площею контакту реагентів, що досягається за рахунок постійного перемішування. Ефективне перемішування визначає повноту проходження процесу переестерифікації і впливає на кількісні та якісні показники виходу дизельного біопалива.

Для досягнення вище зазначеного представлено вдосконалену математичну модель перемішування емульсії у реакторі-змішувачі із використанням дискової форсунки та встановлено основні параметри реактора-змішувача та дискової форсунки.

Пропоновану дискову форсунку можна використовувати для видалення отриманого дизельного біопалива із реактора-змішувача після технологічних операцій переестерифікації та відстоювання. Дискова форсунка дозволяє відкачувати отримане біопаливо починаючи із верхньої частини реактора-змішувача, що унеможливує потрапляння гліцерину в дизельне біопаливо. Застосування дискових форсунок у змішувачах дозволяє виробляти дизельне біопаливо за спрощеною технологією та повністю видаляти його зі змішувача в умовах сільського господарства. В процесі чотирикратного перекачування емульсії по замкнутому контуру та після відповідного відстоювання нами було отримано дизельне біопаливо із кінематичною в'язкістю $4,25 \text{ мм}^2/\text{с}$ та температурою спалаху $125 \text{ }^\circ\text{C}$. Нижча теплота згорання отриманого дизельного біопалива знаходилася на рівні $36,96 \text{ МДж/кг}$. А вихід дизельного біопалива становив $85,6 \%$ від використаної ріпакової олії.

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