MODELLING OF THE HYDRO-MECHANICAL MIXER PARAMETERS
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МОДЕЛЮВАННЯ ПАРАМЕТРІВ ГІДРОМЕХАНІЧНОЇ МІШАЛКИ

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ABSTRACT
It is determined the reactive power to provide hydro-mechanical rotation of the mixer in the process of biodiesel production. It is established that reactive power depends on the flow and pump speed, the density of the mixture of vegetable oil and potassium methylate, the sectional area of the injector nozzles and their number. It is obtained the value of the resistance moment of hydro mechanical mixer depending on the angular velocity and the maximum radius. It is developed the mathematical model of hydro-mechanical mixer rotation, which allows determining the dynamics of the angular velocity of hydro mechanical mixer rotation and its steady-state value.

РЕЗЮМЕ
Визначено реактивну силу для забезпечення гідромеханічного обертання мішалки в процесі виробництва дизельного біопалива. Встановлено що реактивна сила залежить від подачі та частоти обертання насоса, густини суміші рослинної олії та метилату калію, площі перерізу сопла форсунок та їх кількості. Отримано значення моменту опору гідромеханічної мішалки, який залежать від кутової швидкості та максимального радіуса. Розроблена математична модель обертання гідромеханічної мішалки, яка дозволяє визначити динаміку кутової швидкості обертання гідромеханічної мішалки та її усталене значення.

INTRODUCTION
The mechanized work in the agricultural production is impossible without fuel, as up to 80% of manufacturing operations are diesel fuel operated. Therefore, the economic efficiency of agricultural production depends on the cost of diesel fuel *(Golub G. et al 2017)*. One option to reduce costs in agricultural production is the use of own production bio-diesel *(Ivanov B., Stoyanov S., 2016)*. In addition, the use of diesel fuel for operating diesel engines will significantly reduce CO_2 emissions in the agricultural production process.

In the production of bio-diesel one of the key steps is the process of transesterification (Golub G. et al 2015), taking place due to the mixing of vegetable oil and potassium methylate *(Qiu Z. et al, 2010; Ehsan M., Tofajjal H., 2015; Baskar G., Aiswarya R., 2016)*. Mixing determines the completeness of the process of transesterification, which in turn directly affects the quantitative and qualitative yield of biodiesel. As methyl alcohol, catalyst and oil form a two-phase medium, in which the passage of the reaction is slowed down, to intensify the reaction it is necessary to form an emulsion with increased interphase contact area of the reactants, which is achieved due to the constant mixing *(Qiu Z et al 2010; Wulandani D. et al., 2015; Golub G. et al, 2015; Baskar G., Aiswarya R., 2016)*. It is necessary to avoid too intensive mixing, which can lead to the destruction of the interfacial surface and slow down the reaction of transesterification. In addition, intense mixing requires a considerable amount of energy *(Qiu Z. et al, 2010; Golub G. et al, 2015)*. In this regard, improvement of the equipment for biodiesel production based on the mixing of the emulsion components is important.

For the production of biodiesel, the process of transesterification or methanolysis of oils with an alkaline catalyst has become popular *(Golub G. et al, 2015; Ehsan M., Tofajjal H., 2015)*. Studies have shown that methanolysis proceeds in the temperature range from 20 to 70°C with the use of alkaline catalysts (up to 1.5 % of the total volume of emulsion) *(Ehsan M., Tofajjal H., 2015)*. Most often transesterification process has the following parameters: the processing time up to 40 min, the temperature is about 40°C, ratio of methanol to oil is 6 to 1 in moles, catalyst content is up to 1 % of the emulsion volume *(Golub G. et al, 2015; Baskar G., Aiswarya R., 2016)*.

It is established that the quality of the methanolysis reaction depends on hydrodynamic conditions *(Ehsan M., Tofajjal H., 2015)* and requires mixing with a given intensity *(Golub G. et al, 2015)*. It is developed the mathematical model of technological process of transesterification for bio-diesel production on the basis of the possibility theory *(Drahniev S., 2010)* and it is mathematically modelled the adaptive technological process of transesterification of vegetable oils in batch reactors *(Drahniev S., Kukharets S., 2010)*. It is theoretically studied the mixing efficiency when creating in the emulsion stream of the turbulent regime and grounded the constructive parameters of the hydrodynamic separator in bio-diesel production *(Golub G., S. Kukharets, V. Chuba, et al., 2017)*.

The most widely used have become reactors for carrying out the process of transesterification equipped with mechanical mixers *(Drahniev S., 2010)*. It is known the method of bio-diesel production based on hydraulic mixing using stationary atomizers *(Sungwornpatansakul P., Hiroi J., Nigahara Y., et al., 2013; Golub G. et al, 2015)*. In the works *(Drahniev S., Kukharets S., 2010; Drahniev S., 2010; Brásioa A. et al, 2011)* it is stated that one of the disadvantages of mechanical mixing is the formation of areas of emulsion stagnation and substantial energy consumption *(Sungwornpatansakul P. et al., 2013; Mushtruk M. et al, 2013)*. Enzymatic reactors of conventional *(Poppea J. et al, 2015) and rotating (Xua J. et al., 2017)* types are also used, but they have low productivity. Due to lack of the mixing process effectiveness, transesterification doesn't proceed to the full extent, therefore additional operations for flushing *(Alamsyah R., Loebis H., 2014)* and cleaning *(Atadashi I., 2015)* are used, which complicates the technological process of bio-diesel production in terms of agricultural production.

Lately, it has become relevant the use of equipment for biodiesel production with the use of hydro-mechanical mixing that occurs due to departure of a mixture of vegetable oil and potassium methylate from atomizers, resulting in a reactive force, which creates the rotational motion of the mixer with blades, and they in turn provide additional mixing *(Golub G. et al, 2015)*. Thus, there is a double mixing of the emulsion components *(Pavlenko M., Golub G., 2013).*

However, there is currently insufficient research in physical and mechanical properties of bio-diesel and constructive-technological parameters of equipment for the production of bio-diesel, which hinders further enhancement of biodiesel production efficiency. There is also no evidence on the process of biodiesel production using a hydro-mechanical mixing. In this regard, there is the necessity of a theoretical substantiation of the design parameters of the equipment for diesel biofuel production using hydro-mechanical mixing. Determination of the hydro-mechanical mixer parameters in the biodiesel production will allow obtaining data to optimize the operation of complex equipment in vegetable oil transesterification.

MATERIALS AND METHODS

The aim of the research is the development and experimental test of a mathematical model to determine the parameters of hydro mechanical mixer in the production of bio-diesel based on vegetable oils.

Theoretical studies were based on the analysis of the interaction of the blades with the emulsion using the dynamic equations based on Newton's second law. The reactive force of the jet *(Kundu P. et al, 2016)*, which creates a rotary moment of hydro-mechanical blade mixer was determined by the second Newton's law at a constant rate of departure of the jet taking into account the total number of atomizers and parameters of the pump feeding.

To confirm the theoretical studies, the experimental model of the hydro-mechanical mixer was used, the diagram of which is shown in Fig. 1, and the general view – in Fig. 2.

To measure the frequency of rotation of the hydro-mechanical mixer and shaft of hydraulic pump it was used tachometer UT-372. To change the speed of the hydraulic pump shaft, the frequency converter Hitachi-3-G3JX-A4075-EF was used.

RESULTS

To consider the interaction of the hydro-mechanical mixer blades with viscous emulsion medium (components for biodiesel production) the scheme, which is shown in Fig. 3, was used.

The blade of hydro-mechanical mixer, in general case, is set at an angle to the direction of blade movement. The movement of the blade is carried out under the action of reactive force of the jet emitted from atomizers mounted on the ends of the ducts and which are fed with oil mixture with potassium methylate. Viscous medium of the emulsion counteracts the movement of the blade moving under the action of the jet reactive force. As it is known, the blade is influenced by the components of the normal reaction of the viscous medium resistance. Thus, the horizontal component of the normal resistance reaction of the viscous medium opposes the motion of the blade, and the vertical one creates lifting force influencing the blade.

The total reactive force of all jets when supplying the viscous fluid with the help of the pump of volumetric action will be:

$$F_R = \left(\frac{q_H n_H}{60} 10^{-6} \right)^2 \frac{\rho}{\mu S_\Phi n_\Phi}. \quad (1)$$

where $F_R -$ is the reactive force of the jet, H; $q_H -$ pump supply (for gear-type pumps is considered according to specifications), sm^3/turn; $n_H -$ rotational speed of the pump, turn/min.; $\rho -$ the density of the liquid, kg/m^3; $\mu -$ the reduction ratio of the cross-sectional area of the jet at the expiry of liquid from the atomizer, rel. un. *(Kundu P.K. et al, 2016)*; $S_\Phi -$ the actual cross-sectional area of the atomizer, m^2; $n_\Phi -$ number of atomizers, pieces.

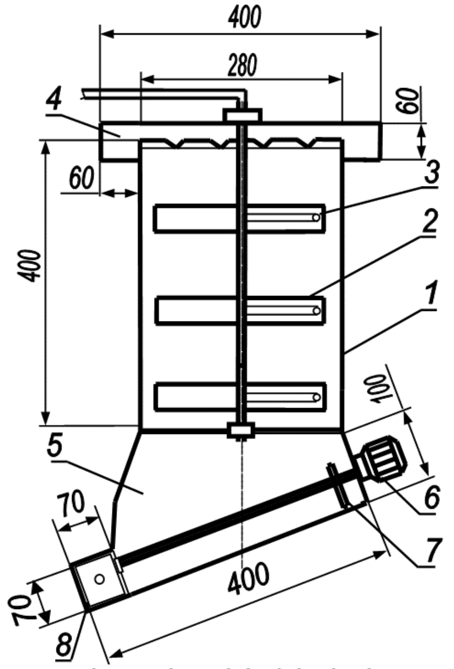

Fig. 1 - Scheme of the experimental model of the hydro-mechanical mixer

1 – the reactor vessel; 2 – hydro-mechanical mixer; 3 – atomizer; 4 – reactor head; 5 – chamber for sediment accumulation; 6 – electric motor; 7 – scraper; 8 – chamber for sediment removal

Fig. 2 - General view of the experimental model of the hydro-mechanical mixer

The resultant of forces of resistance (the total aerodynamic force) is decomposed into two components, the drag (force head) and lifting force. These components help to establish a force that acts in the fluid flow perpendicular to the plane of the scapula. Viscous medium of the emulsion counteracts the movement of the blades moving under the action of jets reactive forces. When moving the blades in a real fluid, in addition to the pressure force on the blade perpendicular to the blade surface and applied in the centre of pressure, they will act directed along the blade forces of friction and resistance dependent on geometric dimensions of the blade. To account for the action of these forces, as well as other unexplored factors, dimensionless coefficients of the changes in the blade lift k_Y and drag force k_X have been introduced. Then, the components of the total aerodynamic force, considering the rotational movement of the blades, can be written as follows:

$$R_{OX} = C_X k_X \frac{\rho \omega^2 r^2}{2} A; \quad (2)$$

$$R_{OY} = C_Y k_Y \frac{\rho \omega^2 r^2}{2} A \quad (3)$$

where C_X, C_Y – accordingly, the coefficients of blade drag and lift force, rel. units; k_Y and k_X – dimensionless coefficients of changes in the blade lift and drag force, rel. units ω – the angular velocity of blades rotation, rad/s; r – the distance from the centre of rotation to the point of force application, m, A – the area of the blade, m^2.

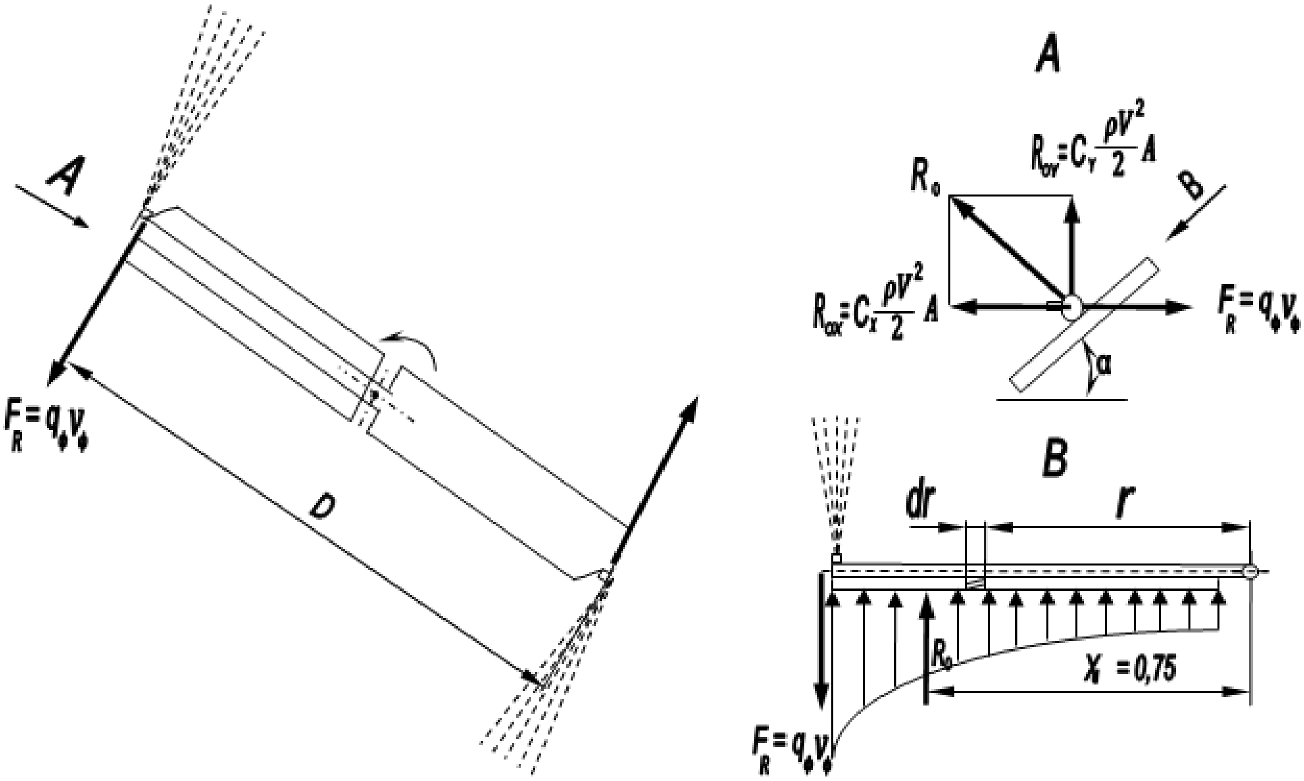

Fig 3 - Interaction scheme of hydro-mechanical mixer blades with the emulsion during the mixing process

During the rotation of the blades the change of drag and lift forces depending on the radius of blade rotation is observed and were determined the elementary drag and lift forces influencing the elementary area of the blade with the length of dr, which is at a distance of r from the axis of rotation. Considering the size of the blade it was determined the elementary moment of resistance dM_R, which is created by the basic drag force on an elementary square of the blade with the length of dr.

Integrating the equation for the elementary moment of resistance due to action of an elementary force of drag, it was obtained the value of the resistance moment depending on the blade rotation radius:

$$M_R = C_X k_X \frac{\rho \omega^2}{8} h r_{max}^4 \quad (4)$$

where r_{max} – the maximum radius of the blade, m, h – the width of blades, m.

The resulting equations have given the opportunity to make the differential equation, which describes the dynamics of hydro-mechanical blade mixer and has the following form:

$$J\frac{d\omega}{dt}=\left(\frac{q_H n_H}{60}10^{-6}\right)^2\frac{\rho}{\mu S_\Phi n_\Phi}\sum_{i=1}^{n} r_{\Phi i}-C_X k_X\frac{\rho\omega^2}{8}h\sum_{i=1}^{n} r_{\max i}^4 \tag{5}$$

Where: $J-$ the moment of inertia of the hydro-mechanical blade mixer, kg m^2; $r_{\Phi i}$ - the radius of installation of the i th atomizer, m; t - mixing time, s.

The differential equation solution allowed us to obtain an equation to determine the dynamics of changes in the angular velocity of hydro-mechanical blade mixer rotation in the following form:

$$\omega=\sqrt{\frac{a}{b}}\frac{\left[\frac{\sqrt{a}+\sqrt{b}\omega_\Pi}{\sqrt{a}-\sqrt{b}\omega_\Pi}\exp\left(2t\sqrt{ab}\right)-1\right]}{\left[1+\frac{\sqrt{a}+\sqrt{b}\omega_\Pi}{\sqrt{a}-\sqrt{b}\omega_\Pi}\exp\left(2t\sqrt{ab}\right)\right]}. \tag{6}$$

where:

ω_Π – the initial angular velocity of rotation of the blades, rad/s;

$a=\frac{1}{J}\left(\frac{q_H n_H}{60}10^{-6}\right)^2\frac{\rho}{\mu S_\Phi n_\Phi}\sum_{i=1}^{n} r_{\Phi i}$ – the ratio of rotational moment to the hydro-mechanical mixer moment of inertia;

$b=\frac{1}{J}C_X k_X\frac{\rho}{8}h\sum_{i=1}^{n} r_{\max i}^4$ – the ratio of resistance to the hydro-mechanical mixer moment of inertia.

In steady state of hydro-mechanical mixer rotation, its angular speed will be $\omega_Y=\sqrt{a/b}$.

According to equation (6), it was designed the graph (Fig. 4) from which it follows that an increase in the frequency of the pump shaft rotation from 700 to 1400 rpm leads to an increase in the steady-state rotation frequency of hydro-mechanical blade mixer from 8.76 to 34 rpm. Steady state of hydro-mechanical mixer rotation begins at time of 0.2-0.4 sec.

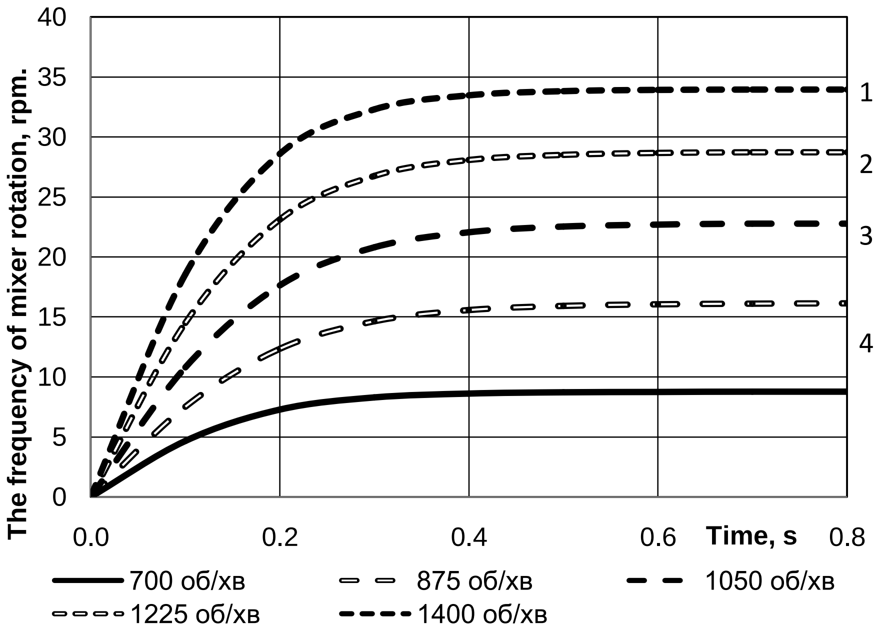

Fig. 4 - Curves of acceleration of hydro-mechanical blade mixer depending on the frequency of pump rotation at an angle of the blades of 60º

1 – 700 rpm; 2 – 875 rpm; 3 – 1050 rpm; 4 – 1225 rpm; 5 – 1400 rpm

On the basis of experimental studies, the dependence of the drag coefficient on the frequency of pump rotation (Fig. 5) was found, which allowed us to obtain complete coincidence of the experimental data with the theoretical dependence, which relates steady frequency of mixer rotation and the rotational speed of the pump.

For the dependence of the hydro-mechanical mixer established rotation frequency on the angle of the blades, the level of approximation of theoretical and experimental data, estimated by the index of determination is 0.93 rel. units (Fig. 6).

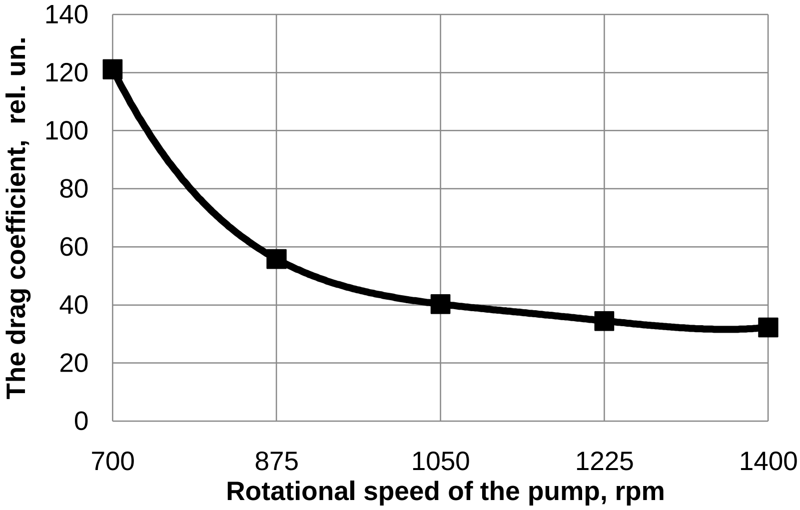

Fig. 5 - The graphical dependence of the drag coefficient on the frequency of pump rotation

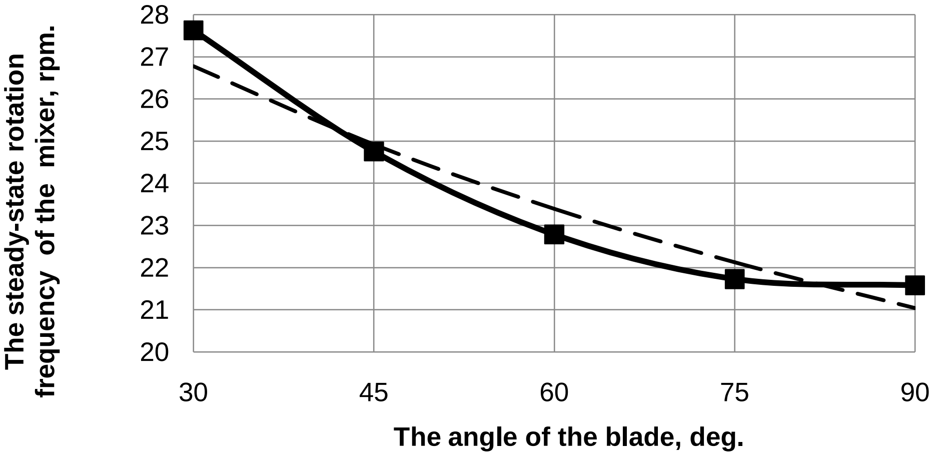

Fig. 6 - The graphical dependence of the mixer steady-state rotation frequency on the angle of the blades

.... – theoretical values; – experimental values

The proposed calculation of equipment for the production of bio-diesel gave the ability to determine the equipment design parameters (Fig. 7) for biodiesel production for agricultural needs. The use of hydro-mechanical mixer for biodiesel production allows obtaining biodiesel according to the simplified technology in agricultural production.

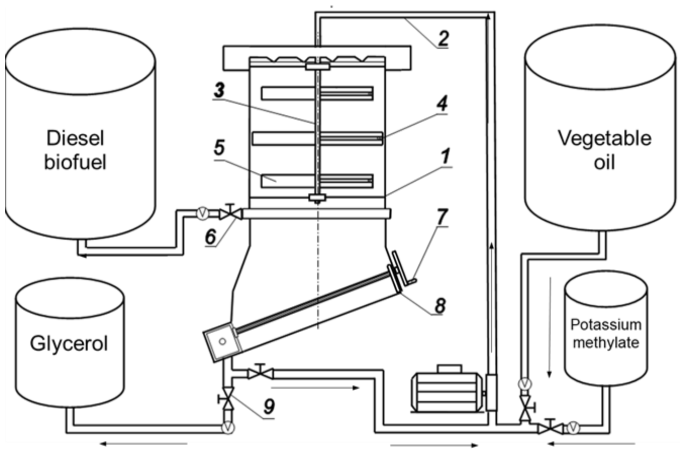

Fig.7 - Diagram of the biodiesel production plant

1 – gravity separator body; 2 – emulsion intake pipe; 3 – hydro jet mixer; 4 – atomizer; 5 – blade; 6 – bio-diesel removal cock; 7 – mechanism for glycerol precipitate removal; 8 – scraper for glycerine precipitate removal; 9 – cock for glycerine precipitate removal

CONCLUSIONS

The developed mathematical model for determining the angular velocity of rotation of hydro-mechanical mixer, depending on the pump parameters, density of vegetable oil, the actual cross-sectional area of the atomizers and their number, as well as the height and radius of the blades allows determining the dynamics of the hydro-mechanical mixer angular velocity of rotation and its steady-state value.

It is established that with increasing pump speed from 700 to 1400 rpm, the rotation frequency of hydro-mechanical mixer changes from 8.76 to 34 rpm and the steady state occurs in 0.2-0.4 sec.

On the basis of experimental studies was found the dependence of the drag coefficient of the pump rotation frequency.

The results of the conducted theoretical and experimental studies of hydro-mechanical mixer for vegetable oil and potassium methylate allowed developing the methods for engineering calculation of the mixer structural and technological parameters.

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