MODERNIZATION OF THE POWER SUPPLY SYSTEM OF A DIESEL POWER PLANT

Serhiy Burlaka[1]
Natalia Telekalo[2]

DOI: https://doi.org/10.30525/978-9934-26-221-0-10

Abstract. The research is devoted to solving important tasks of interdisciplinary research work on the topic: «Development of scientific and technical support for energy autonomy of the agro-industrial complex based on environmentally efficient use of agrobiomass for biofuel production», state registration number 0122U000844, implementation of which is planned for 2022–2024 at the expense of the state budget of Ukraine.

This paper considers topical scientific and technical issues of improving the efficiency of machine units when working with mixed fuels. One of the most promising alternative fuels is biofuels, the use of which will reduce the consumption of petroleum fuels and reduce corrosion emissions into the atmosphere.

A review of the literature sources of modern power systems and equipment using biofuels and their mixtures, the impact of fuel mixtures on engine operation and analysis of mathematical models for calculation by the methods of Lyshevsky O. S. and clarification of prof. Razleytseva M. F.

An improved diesel engine power system has been developed, which electronically controls the composition of the dosed fuel mixture, a mixer for mixed fuel supply to the machine unit has been developed, the operation of the machine-tractor unit (MAT) model has been confirmed, and AIT physical and mathematical models have been developed. A method for calculating the continuity of the working fluid flow in the characteristic areas of modern power supply systems has been developed.

[1] PhD in Engineering, Senior Lecturer,
Vinnytsia National Agrarian University, Ukraine
[2] Candidate of Agricultural Sciences, Associate Professor,
Vinnytsia National Agrarian University, Ukraine

The geometric parameters of the Savonius rotor of the developed mixer are calculated and optimized to the most appropriate design solution.

The aim of the study is to increase the efficiency of biofuel use in diesel power plants by improving the fuel system of the fuel mixer.

Research methods include theoretical and experimental studies of the process of obtaining and supplying biofuels using a mixing device, comparative studies of diesel power plant in bench conditions and operating conditions on this fuel using modern technical measuring instruments and methods of processing these data on personal computers using standard application packages Compass, FlowVision.

1. Introduction

One of the main problems of livelihood of modern society is the availability of sufficient energy resources. The world's energy balance is formed mainly on the basis of three non-renewable hydrocarbon energy sources – natural gas, oil and coal. The use of these sources causes a number of problems: limited available reserves, difficult conditions of production and transportation, the constant rise in prices, the deteriorating environmental situation. The transition to the use of motor biofuels can partially solve these problems.

The reduction of the world's oil reserves, and hence the products of its refining, as well as the deterioration of the environmental situation raises the question of the use of alternative fuels for internal combustion engines. One of these fuels is biofuels, the use of which will reduce the consumption of petroleum fuels and reduce the amount of aggressive emissions into the atmosphere.

Many fuel parameters affect the efficiency of the engine, including density, kinematic viscosity, fractional and chemical composition. Viscosity and fuel density have a significant effect on the quality of the spray, the amount of cyclic feed and the completeness of combustion.

Widespread use of a new type of fuel is impossible without a comprehensive, comprehensive analysis to study the impact of the values of biofuels on the reliability of the elements of fuel equipment. And this in turn affects the technical, economic and operational performance of the internal combustion engine.

2. Features of operation of machine units with the use of fuel mixtures

2.1 Analysis of power supply systems for tractor engines using fuel mixtures

One way to improve the performance of diesel engines and reduce the consumption of fuel derived from petroleum is to mix diesel fuel with biofuels.

Analysis of the literature [1; 2; 3], found that the use of mixtures with different percentages differently affects the performance of the engine. Moreover, performance depends on the composition of the mixture and the brand of engine. Sometimes the results of research lead to the opposite result. The most common raw materials for the production of diesel fuels today are oils: rapeseed, soybean, palm and others.

The use of biofuels is complicated by the fact that the fuel systems of diesel engines are not designed and adapted to this type of fuel. Therefore, at the first stage we will analyze the design solutions of modern power supply systems for diesel engines running on a mixture of fuels (mineral diesel and biofuels).

The simplest way to solve the use of biofuels as motor fuel is to upgrade the standard fuel system of a diesel engine.

Designs of developed fuel systems for the use of biofuels do not provide the required percentage of mineral and vegetable fuels, taking into account their temperature, depending on the load and speed of the engine [4; 5].

Due to their physical and chemical properties, biofuels do not meet the requirements for diesel fuel. Efficient operation of diesel engines, without significant changes in the design, is possible only when working on biomineral fuel – a mixture of biological and mineral diesel fuel. To do this, additional elements are introduced into the standard engine power supply system, ie the power supply system is improved with certain design changes, such as: vegetable fuel tank 11, filter 13, mixer-dispenser 15 (Figure 1) [6].

The engine is started on mineral fuel. The solenoid valve 14 is closed and the fuel from the tank 1, passing through the open solenoid valve 20 and the filter 3 coarse cleaning and the mixer-dispenser 15, is fed by the fuel pump 5 to the filter 4 fine cleaning, and then into the filling cavity of the high pressure fuel pump 6 and then the injector 8 is injected into the cylinder 9 of the engine.

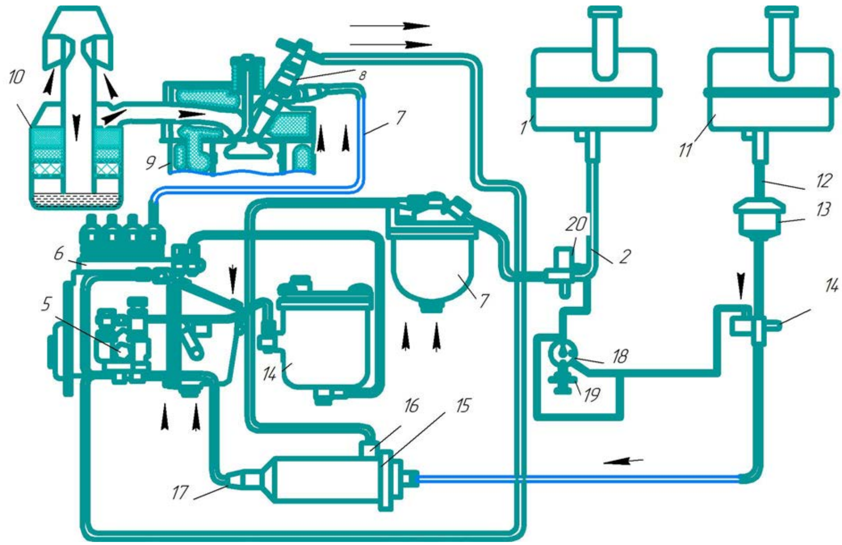

Figure 1. Diesel engine power system for biomineral fuel:
⟶ biofuel supply; – – –► supply of mineral fuel;
·······► supply of biomineral fuel;
1 – tank for mineral fuel; 2 – fuel pipelines; 3 – FGO; 4 – FTO;
5 – fuel pump; 6 – PNVT; 7 – high pressure pipelines; 8 – nozzle;
9 – cylinder; 10 – air purifier; 11 – tank for vegetable fuel;
12 – fuel line of vegetable fuel; 13 – filter; 14, 20 – solenoid valves;
15 – mixer-dispenser; 16,17 – fittings; 18 – switch; 19 – power supply

After heating, the switch 18 includes a solenoid valve 14, providing vegetable fuel from the tank 11 through the filter 13 into the mixer-dispenser 15. Mineral fuel is fed to the mixer-dispenser through the line: tank 1, solenoid valve 20, coarse filter 3, mixer-dispenser 15. In the mixer-dispenser both types of fuel are mixed and the resulting biomineral fuel enters the filling cavity of the high pressure fuel pump 6, then the injector 8 is injected into the cylinder 9 of the engine.

The disadvantages of this power system include the inability to adjust the percentage of required biofuels and diesel fuel based on the model of the load speed of the diesel engine.

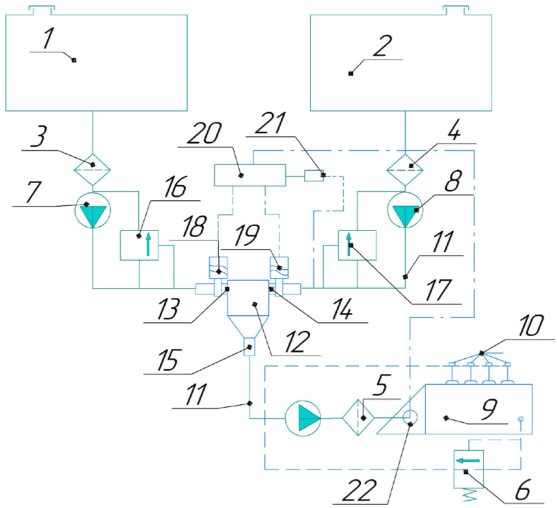

Figure 2. Scheme of a two-fuel power system

Another considered two-fuel power supply system (Figure 2) provides the supply of mixed fuel in the optimal percentage depending on the load on the machine-tractor unit [7].

The analyzed two-fuel power supply system of the diesel engine includes a tank of mineral fuel 1, a tank of vegetable fuel 2, fuel filters 3, 4, 5, an electric pump of mineral fuel 7, an electric pump of vegetable fuel 8, a high pressure fuel pump 9 complete with centrifugal frequency regulator rotation and check valve 6, injectors 10, fuel lines 11 and the mixer 12, which has two inlet 13, 14 and one outlet 15 channels, while in the inlet channels 13, 14 installed pressure valves 16, 17 in front of the dispensers 18, 19, electrically with connected via an electronic control unit 20 to the vegetable fuel temperature sensor 21 and the load-speed sensor 22.

The two-fuel engine power system works as follows.

The engine is started and warmed up on mineral fuel. The electric fuel dispenser 18 is fully open, and the vegetable fuel dispenser 19 is completely closed. Mineral fuel from the tank 1, through the coarse filter 3, electric pump 7 through the fuel lines 11 and the electric dispenser 18 is fed to the mixer 12, fine filter 5, then the high pressure fuel pump 9 and injectors 10 is injected into the engine cylinders.

After heating on mineral fuel include an electric pump 8, which supplies vegetable fuel from the tank 2 through the fuel filter 4 and the electric dispenser 19 in the mixer 12. The electric dispenser 19 controlled by the electronic control unit 20, depending on the temperature of vegetable fuel detected by the sensor 21, automatically regulates the flow, providing the required percentage of mineral and vegetable fuels in the mixture when the temperature of the vegetable fuel changes. Mineral fuel is fed to the mixer 12 similar to the operation of the diesel engine in the start and warm-up mode. In the mixer 12 both types of fuel are mixed and the resulting diesel blend fuel is fed through a fine filter 5 into the high pressure fuel pump 9 and then injected into the cylinders by injectors 10.

When changing the operating mode, the load-speed sensor of the engine 22 is triggered and sends a signal to the electronic control unit 20. The command signal from the unit 20 enters the electrical circuit of the dispensers, which, when activated, change the percentage of mixed fuel components.

By maintaining a constant fuel pressure at the inlet to the mixer valves 16, 17, the outlet bypass valve 6, electric dispensers 18, 19 provides the exact percentage of mixed fuel components depending on the load-speed mode of operation of the engine and vegetable fuel temperature.

The advantages of this system include the fact that new elements are used (dispensers, actuator, controlled and adjustable rods), which provide the desired ratio of the composition of the mixture depending on the load-speed mode of the engine.

The disadvantages of this system include the fact that it can not provide autonomous operation of the engine only with the use of biofuels.

Thus, by introducing new elements (dispensers and mixers) into the power supply system, the error is reduced while providing the required percentage of blended fuel components by providing the same pressure at the inlet to the dispensers of vegetable and mineral fuels, when changing the load speed and temperature vegetable fuel.

2.2. Analysis of designs of diesel and biofuel mixers

Mixing of liquid media is a very common process in industry. It is used for the preparation of emulsions, suspensions, solutions, etc., to intensify thermal, mass transfer and chemical processes [8]. As a result of mixing, dispersion of one phase into another is achieved, uniform distribution of system components by the volume of the apparatus, restoration of the contact surface of the phases, providing new portions of the substance in the contact zone, reducing the thickness of the boundary layer.

Mixing of liquid media is carried out using: mechanical stirrers; compressed gas (pneumatic); in pipelines, most often due to the installation of turbulent inserts in them; nozzle; pumps (Figure 3).

The most common mixing with mechanical stirrers.

Mechanical stirrers are solid bodies that create rotational (rarely reciprocating or oscillating) motion in liquids. Mechanical mixing, as a rule, is carried out in those devices in which technological processes are carried out directly: reactors, neutralizers, etc.

The main characteristics of the mixing process are the efficiency and intensity of mixing.

The mixing efficiency characterizes the quality of the process. When obtaining suspensions, mixing is determined by the uniformity of the distribution of the solid phase in the liquid, and for heat and mass transfer processes – the ratio of heat transfer and mass transfer coefficients, respectively, achieved with and without mixing.

The quality and efficiency of mixing depends on the design of the device, as well as on the amount of energy supplied to the unit volume of the medium [7–9].

The intensity of mixing is determined by the time of achievement of the specified technological result. At higher mixing intensities, the time to achieve the desired effect is reduced, but large specific capacities are required.

At the same time, increasing the intensity of mixing increases the productivity of equipment, reduces specific capital costs. In the feasibility study, an option should be chosen that provides a minimum amount of energy and capital costs per unit volume of medium that is mixed when the desired efficiency is achieved.

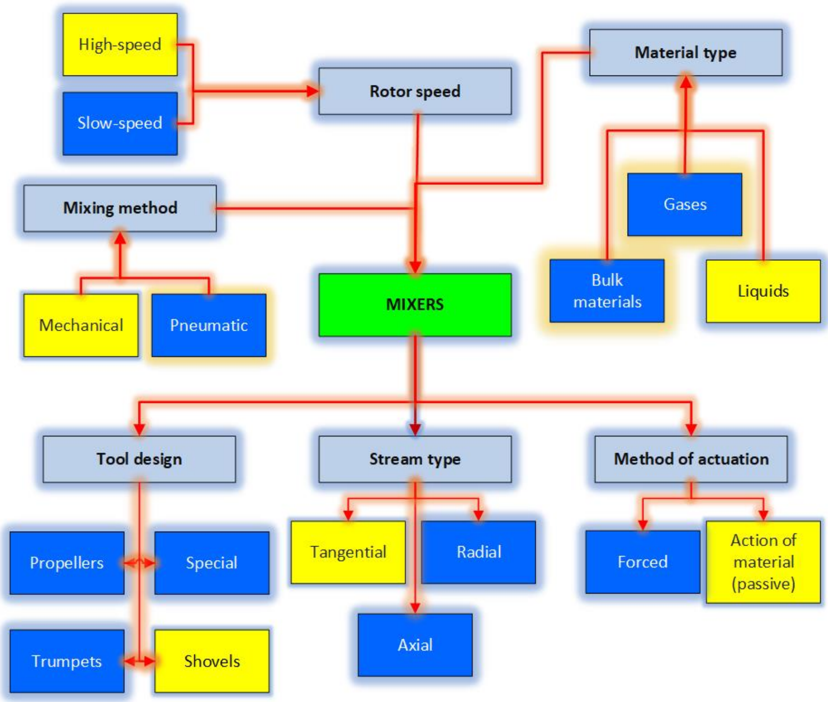

Figure 3. Classification of faucets

Consider and analyze the work of some of them. The mixer of components of biomineral fuel with the active drive (Figure 4) works as follows [10].

The components of the biomineral fuel are mixed through the inlet pipe 2 and 3 placed on the front cover 9 of the housing 1, where they enter the working cavity 14 of the mixer. There is an intensive mixing of mineral and biological components of the main 5 and additional 6 impellers, which rotate at different frequencies. Different speeds 5 and 6 are possible due to the fact that the main impeller 5, made in the form of a «wheel» with blades 16, rigidly mounted on the shaft 7 of the drive 8. Additional impeller 6 is kinematically connected to the shaft 7 through a planetary gear containing a crown gear 17, pressed inside the housing 1, three satellites 18, the carrier 19, rigidly connected to the additional impeller 6 and the sun gear 20 mounted on the slots of the rear end of the shaft 7.

The finished mixture (diesel mixed fuel) from the working cavity 14 of the mixer through the holes 13 in the housing 1 enters the mixed cavity 15, passing through the calming mesh 12 and the cavity 11, exits the mixer through the outlet of the mixture 4 in the conical cover 10. the quality of mixing of the components is provided by different speeds of the main 5 and additional 6 impellers.

The general view of the mixer with the active drive established on the engine of the MTZ-82 tractor is presented in Figure 4. The disadvantage of this device is the complexity of the design, high production costs and a significant increase in the inertia of the system, which creates engine failures and reduces the performance of AIT.

Therefore, the use of this mixer is not advisable.

You should also pay attention to conventional instantaneous faucets. One of these is shown in Figure 5, where the fuels are mixed (mineral and vegetable oil) through the input channels of components 9 and 10, as well as electro-dispensers 3 and 4, placed on the cover 1, enter the working cavity 11 of the mixer. From the working cavity 11 through the channel in a special bolt components enter the mixed cavity 12. Mixed components, passing through the labyrinths of metal stuffing (stainless steel shavings) 8 constantly change speed and direction of movement, thereby intensively mixed. Prepared mixed fuel from the cavity 12, passing through the grid-calmer 13, exits the mixer through the outlet channel of the mixed fuel 14 and enters the U-shaped channel PNVT and then to the engine injectors [11].

The disadvantage of such mixers is the inability to adjust the required percentage of fuels depending on the operating modes of the engine and the load-speed characteristics of the AIT.

Due to the fact that biofuels from vegetable oils have a higher density, viscosity and surface tension coefficient, it is difficult to use it in the regular diesel power supply system [12; 13]. Among other things, the mixture is formed of insufficient quality due to the weak turbulence of the jets coming out of the spray holes. This increases the duration of fuel supply, degrades the uniformity of the structure of the fuel torch, reduces the angle of its opening, leads to coking of the spray channels. One of the effective ways of adaptation is the modernization of regular injectors.

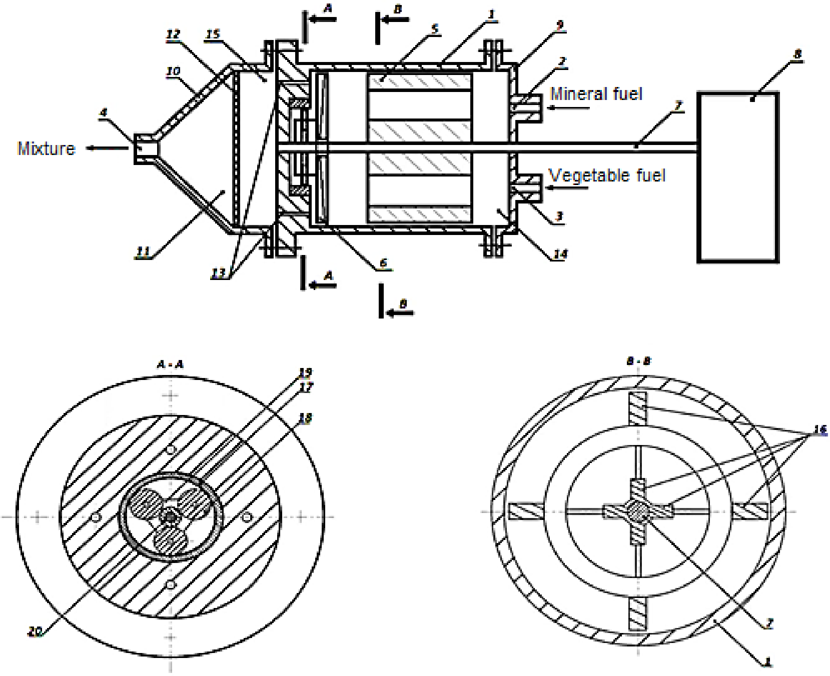

Figure 4. Scheme of the mixer of biomineral fuel components with active drive

In Figure 6 schematically shows the spray assembly of the injector for burning viscous fuel, which contains a conical nozzle nozzle 1 (Figure 6) with a central fuel nozzle 2 and mounted around 1 annular nozzle 3, forming a channel 4 for air supply [14]. At the output end of the nozzle 1 is made of a conical edge 5, which forms at the intersection with its outer surface a sharp edge. The ratio of the radius R of this edge to the radius r_c of the fuel nozzle 2 is determined by:

$$\frac{R}{r_c}=1+1,41K\sqrt[4]{\frac{b_3}{r_c^3\cos^2\pm}} \qquad (1)$$

b – width of the channel 4 for air supply, mm; *α* – the angle forming the surface of the conical nozzle nozzle, deg; *K* – variable numerical coefficient

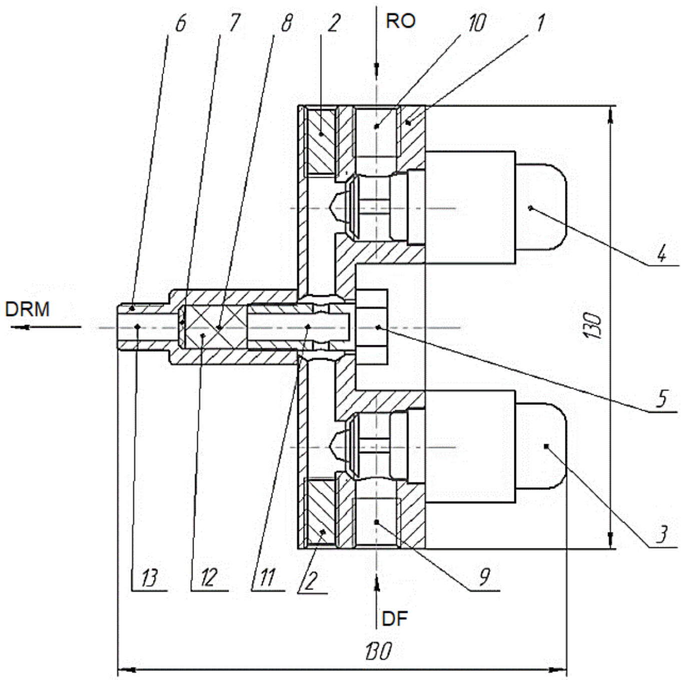

Figure 5. Mixer-dispenser of vegetable oil and mineral diesel fuel

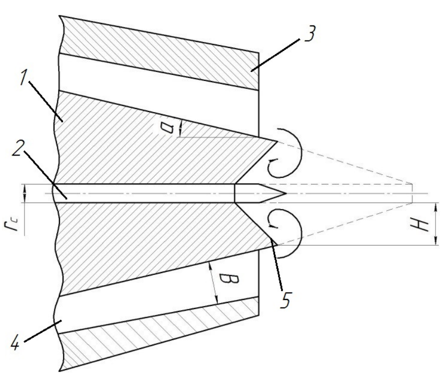

Figure 6. Scheme of the nozzle spray (explanation in the text)

that determines the range of optimal modes of operation of the nozzle (K_1 = 0,93-1,14).

During operation, the fuel is fed into the nozzle 1 and sprayed through the nozzle 2, interacting with the air stream coming from the channel 4. In the area of the conical recess 5 forms a vortex of viscous fuel, which intensifies mass transfer in the spray zone and improves stability. nozzles when changing the load. Variations in the coefficient K are determined by the viscosity of the fuel.

The described method of adapting the injector of a diesel diesel engine allows to optimize the performance of its working process when working on viscous fuel, which is biofuel from vegetable raw materials, but is only an improving method for running the engine on alternative fuels and does not allow to regulate and create fuel mix.

Each of the considered options does not satisfy operation of the engine in these or those parametric characteristics. The task is to create a fundamentally new device for creating blended fuel.

3. Theoretical research on the efficiency of machine units using biofuels and mixtures

3.1. Substantiation of the diesel engine power supply system for fuel mixture operation

Diesel fuel systems are classified according to many criteria. Therefore, the general classification is quite complex. The design features, which are due to the methods of fuel supply and spraying, are mainly considered. In Figure 7 shows the general classification of existing fuel systems according to the above-mentioned features.

The calculated scheme of the power supply system of the diesel engine is presented in Figure 8.

ECU 12 receives initial pressure data T_o and temperature P_o environment, signal on the position of the fuel supply lever 13 $W_{пп}$ – position of the fuel supply lever from the corresponding sensor, signal on the engine crankshaft speed $n_д$ from the sensor 14, signal on the coolant temperature $T_{ох}$ from the sensor 15 and the capacitive sensor to determine the composition of the mixture 11.

The engine is warmed up on diesel fuel and is set by the temperature of the coolant $T_{ох}$. The throttle line responsible for the supply of diesel fuel is open (U1 = 1), the supply pump is 2 (U4 = 1), and the biofuel 4 is closed (U2, U3 = 0). Since the physico-chemical characteristics of BP have differences from DP, it is necessary to heat the BP to balance the indicators. Since the filter-mixer 8 is placed directly on the biofuel engine and the mixture is heated to the appropriate temperature.

Data on fuel temperatures in the filter-mixer 8 $T_{сум}$ are received in ECU 12. Accordingly, if the temperature of the coolant $T_{ох}$ and the temperature

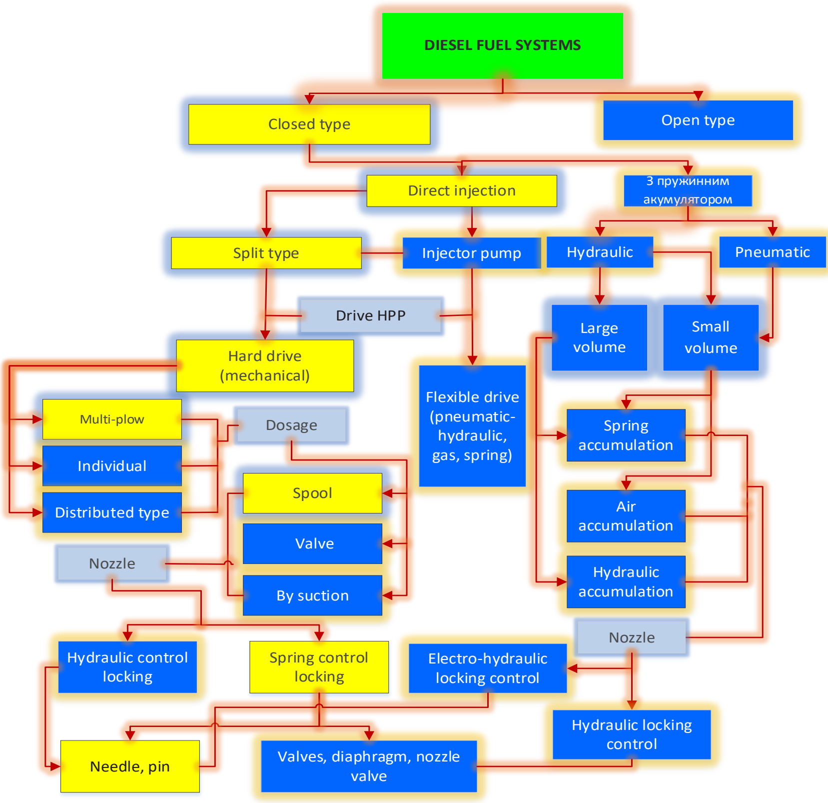

Figure 7. Classification of fuel systems for diesel engines

$T_{сум}$ have reached the minimum allowable value, the diesel engine switches to fuel mixture, the composition of which is regulated and specified by capacitive sensor 11 (U5 = 1), the biofuel supply pump 6 is switched on (U3 = 1).

In ECU 12 the values of the percentage of $n_{БП}$ and cyclic supply qц of the fuel mixture are selected. Next, the information $n_{БП}$ comes to the choke 4, the signal with the value of $q_ц$ comes to the ECU 12.

During the operation of the engine chokes 4 regulates the quantitative ratio of BF, PSU and fuel mixture. During warm-up, the line of the throttle

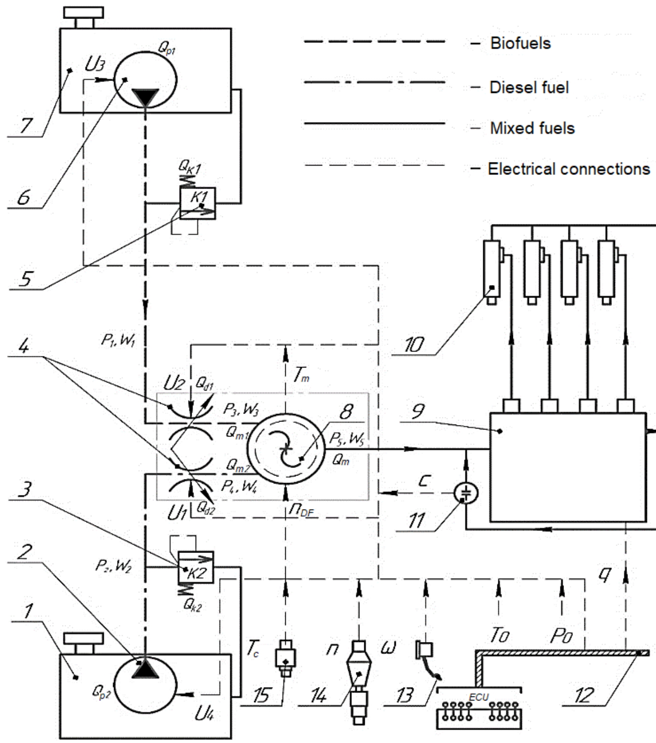

Figure 8. Diesel engine power system with electronic control of the composition of the metered fuel mixture [59]: 1 – fuel tank for BF; 2 – diesel fuel supply pump (DP); 3 – safety valve DP; 4 – chokes DP and BP; 5 – safety valve BP; 6 – biofuel supply pump (PSU); 7 – fuel tank for PSU; 8 – filter-mixer; 9 – PNVT; 10 – nozzles; 11 – capacitive sensor for determining the composition of the mixture; 12 – electronic control unit; 13 – fuel supply control lever; 14 – crankshaft speed sensor; 15 – coolant temperature sensor

DP 4 (U1 = 1) is completely open and the PSU (U2 = 0) is closed. Further, depending on the load-speed indicators and operating modes, the position of the chokes 4 for both fuels varies depending on the percentage of the mixture which is regulated by the capacitive sensor 11 (U5 = 1) [17].

Before stopping the engine with ECU signal to the throttle control 4 to set in a position that provides 100% DP (U1 = 1), while the pump 6 is turned off (U3 = 0), and the biofuel supply line of the throttle 4 is blocked (U2 = 0). The fuel mixture from the return pipe is fed to the PNVT 9, the supply system (low pressure fuel lines after the mixer, high pressure fuel lines, PNVT, injectors) is filled with BF. This will ensure the next easy start of the MA [18]. The engine is ready to stop. The diesel fuel supply system can be refilled immediately before stopping.

A feature of the control during the transfer to work using the mixture and the regulation of its percentage is the need to control the mixer and elements of the system of unused fuel. Diesel and biofuels are fed to the mixer from individual pipelines and pumps. Depending on the position of the control unit, a mixture of fuels with the appropriate percentage composition is created in the mixer and fed to the PNVT.

A low-pressure biofuel supply line has been added to the developed power supply system, where the pump is controlled. Biofuel heating is mandatory during its use, especially at low ambient temperatures. Thus, when heated from 20 °C to 50 °C, its viscosity decreases by about 51%. Indicators of density, surface tension, etc. also change, but not significantly. On a cold engine, the process of evaporation and combustion of fuel deteriorates and the probability of fuel entering the crankcase, where it dilutes the oil, increases. The impact of biofuels on lubricants is more negative than that of diesel fuels. The properties of biofuels determine its greater ability to coking, which is especially evident during poor fuel spraying (on unheated biofuels) [19].

3.2. Development of a mathematical model of a diesel engine power system for operation on a mixture of fuels with chokes to regulate the composition of the metered fuel mixture

The proposed diesel engine power supply system for two types of fuel consists of a fuel supply and mixing system (low pressure), a high pressure system.

When compiling a mathematical model taking into account the results of previous studies [20–22], the following assumptions were made:

1) the density, viscosity and flow rate of the working fluid do not depend on temperature due to the operation of the fuel supply system at a steady temperature;

2) pressure losses in the internal channels of the fuel supply system are not taken into account;

3) the coefficient of flexibility of the fuel does not depend on the pressure and content of the gas component, as in the steady state of the fuel system, its value changes slightly;

4) the coefficient of leakage and overflow of fluid in the components of the fuel supply system is constant and does not depend on the size and shape of the gaps;

5) the distance between the elements of the fuel supply system is insignificant, which allows us to consider it as a system with concentrated parameters and not to consider the impact of wave processes [23];

6) pulsation of the pump supply, taking into account its significant frequency, does not cause excitation of pressure fluctuations in the fuel supply system;

The operation of the low-pressure subsystem is described by the equations of continuity of the working fluid flows [23]. The equation of continuity of working fluid flows in the diesel pump line has the following form (2):

$$Q_{P1} = Q_{d1} + Q_{\cos t1} + Q_{d1} + Q_{k1} \tag{2}$$

Q_{P1} – diesel pump supply; Q_{d1} – fuel consumption through the diesel throttle; Q_{k1} – fuel consumption through the check valve; Q_{cost1} – fluid loss in the diesel fuel line; Q_{d1} – the flow rate of the working fluid caused by the deformation of the cavities filled with the working fluid under the action of pressure p_1.

Equation of cost balance in the biofuel pump line (2):

$$Q_{P2} = Q_{d2} + Q_{\cos t2} + Q_{d2} + Q_{k2} \tag{3}$$

Q_{P2} – biofuel pump supply; Q_{d2} – fuel consumption through the biofuel throttle; Q_{cost2} – fluid loss in the biofuel line; Q_{d2} – the flow rate of the working fluid caused by the deformation of the cavities filled with the working fluid under the action of pressure p_2.

The level of the balance of fuel consumption in the cavity 3 (3):

$$Q_{d1} = Q_{zm1} + Q_{\cos t3} + Q_{d3} \tag{4}$$

Q_{zm1} – consumption at the entrance to the diesel fuel mixer; Q_{cost3} – fluid loss to leaks in the highway 3; Q_{d3} – the flow rate of the working fluid caused by the deformation of the cavities filled with the working fluid under the action of pressure p_3.

The level of the balance of fuel consumption in the cavity 4 (4):

$$Q_{d2} = Q_{zm2} + Q_{\cos t4} + Q_{d4} \tag{5}$$

Q_{zm2} – consumption at the entrance to the diesel fuel mixer; Q_{cost4} – loss of fluid to leaks in the highway 4; Q_{d4} – the flow rate of the working fluid caused by the deformation of the cavities filled with the working fluid under the action of pressure p_4.

Mixer cost balance equation (5):

$$Q_{zm} = Q_{zm1} + Q_{zm2} + Q_{\cos t5} + Q_{d5} \tag{6}$$

Q_{zm1} – consumption at the entrance to the diesel fuel mixer; Q_{zm2} – consumption at the entrance to the biofuel mixer; Q_{cost5} – fluid loss in the mixer; Q_{d5} – the flow rate of the working fluid caused by the deformation of the cavities filled with the working fluid under the action of pressure p_5.

Actual fuel consumption from the i-th unregulated pump is determined according to the expression (6) [23]:

$$Q_{Pi} = q_{Hi} \cdot n_{Hi} \cdot \eta_{rev}, i = 1..2 \tag{7}$$

$q_{нi}$ – working volume of the i-th pump; $n_{нi}$ – the speed of rotation of the shaft of the i-th pump; η_{rev} – volumetric efficiency of the i-th pump.

Losses of fluid leakage through the gaps in the joints of parts of hydraulic equipment and hydromechanisms are calculated as the flow of fluid through a flat slit under the accepted assumptions:

– the shape of the surfaces forming the flow channel is perfect;
– surface roughness is not taken into account;
– the gap is symmetrical.

In this case, the flow of fluid for leakage through the passage section of the gap will be determined by the following dependences (8):

$$\begin{aligned} Q_{cost1} &= \sigma_1 \cdot p_1; \\ Q_{cost2} &= \sigma_2 \cdot p_2; \\ Q_{cost3} &= \sigma_3 \cdot p_3; \\ Q_{cost4} &= \sigma_4 \cdot p_4; \\ Q_{cost5} &= \sigma_5 \cdot p_5; \end{aligned} \tag{8}$$

$\sigma_1, \cdot\sigma_2, \cdot\sigma_3, \cdot\sigma_4, \cdot\sigma_5$ – coefficients of fluid leakage from cavities under pressure p_1, p_2, p_3, p_4, p_5 in accordance.

According to the values of leakage coefficients σ_i· fluids through the gaps can be determined by the following formula (9):

$$\sigma_i = \frac{b_{gap} \cdot \delta_{gap}^3}{l_{gap}} \cdot \mu\left(p_i, t_i^\circ C\right) \cdot l_0 \pm V_{gap} \cdot b_{gap} \cdot \delta_{gap}, i = 0..4 \tag{9}$$

b_{gap} – the width of the fluid leakage gaps in the direction perpendicular to the direction of fluid flow in the i-th section of the hydraulic system; δ_{gap} – the depth of the fluid leakage gaps in the i-th section of the hydraulic system; l_{gap} – the length of the fluid leakage gaps in the direction of fluid flow in the i-th section of the hydraulic system; $\mu\left(p_i, t_i^\circ C\right)$ – dynamic viscosity of the fluid, which depends on the pressure and temperature of the working fluid; V_{gap} – the relative speed of movement of one of the walls, which sets the boundary of the gap. The sign «+» refers to the case when the wall moves in the direction of the zone of reduced pressure, «-» – in the opposite direction.

The change in viscosity μ(p,t°C) depending on the pressure p and the temperature t°C is determined according to the dependence (10) [24]:

$$\mu\left(p_i, t^\circ C\right) = \mu_{50,p_0} \cdot \exp\left(b_p \cdot p_i\right) \cdot \left(\frac{50}{t^\circ C}\right)^{n_B}, i = 0...7 \tag{10}$$

b_p – coefficient that depends on the properties of the working fluid, b_p = 0.0023 … 0.0033; n_B – the initial viscosity of the liquid.

The costs that occur when the deformation of the volumes of hydraulic cavities filled with fluid through changes in pressure in these cavities are determined by the dependences (11) [24]:

$$Q_{d.i} = K_i(p_i) \cdot W_i \cdot dp_i / dt, i = 0...5 \tag{11}$$

$K_i(p_i)$ – coefficients of pliability of the corresponding highways and cavities of this hydraulic system; W_i·– the volume of the i-th fuel line.

Study of the dependence of the coefficient of pliability on pressure $K_i(p_i)$ engaged in many researchers both experimentally and theoretically. As a result of their research [24], the formula for calculating the coefficient of ductility, which takes into account the total deformation of the working fluid as a gas-liquid mixture under isothermal compression, and the pipeline (cavity) (12):

$$K_i\left(p_i\right) = \frac{1}{E_{см}\left(p_i\right)} + Com\, i = 0..7 \tag{12}$$

C_{om} – volumetric stiffness of the pipeline (cavity) through which the working fluid passes; Ecm – modulus of elasticity of the gas-liquid mixture.

The volume stiffness of the pipeline can be reduced to linear stiffness by expression (13):

$$C_{mi} = \frac{F_{Ki}^2}{C_{om}}, \qquad (13)$$

C_{mi} – the linear stiffness of the i-th cavity is given; F_{Ki} – the structural area of the end of the loaded cavity.

The modulus of elasticity of the gas-liquid mixture is calculated depending on (14):

$$E_{cm}\left(p_i\right) = \frac{E_{zh} \cdot \left(1 + \overline{V_g}\,\frac{p_{am}}{p_i}\right)^{\frac{1}{k}}}{1 + E_{zh} \cdot \left(\frac{\overline{V_\Gamma}}{k \cdot p_i}\right) \cdot \left(\frac{p_{am}}{p_i}\right)^{\frac{1}{k}}}, i = 0..7, \qquad (14)$$

E_{zh} – fluid modulus; $\overline{V_g}$ – specific content of undissolved gas in the liquid; p_{am} – atmospheric pressure under normal conditions; k – polytrope index.

Equation of fuel consumption through the throttle 1 (15):

$$Q_{d1} = \mu \cdot F_{d1}(U_2) \cdot \sqrt{\frac{2}{\rho_{DF}}} \cdot \sqrt{P_1 - P_3} \cdot \sin(P_1 - P_3) \qquad (15)$$

Q_{d1} – fuel consumption through the diesel throttle; $\propto$ – dynamic viscosity of diesel fuel; F_{d1} – the cross-sectional area of the throttle; ρ_{DF} – density of diesel fuel; P_1, P_3 – pressure before and after the throttle.

Equation of fluid flow through the safety valve Q_{k1} (16):

$$Q_{k1} = \left| \begin{array}{c} 0, p_1 < p_{kl} \\ \mu \cdot F_{k1} \cdot \sqrt{\frac{2}{\rho}} \cdot \sqrt{p_1 - p_0} \cdot sign\left(p_1 - p_0\right), p_1 \geq p_{kl} \end{array} \right. \qquad (16)$$

Q_{k1} – fuel consumption through the non-return valve of diesel fuel; μ – dynamic viscosity of diesel fuel; F_{k1} – the cross-sectional area of the valve; P_{BF} – density of biofuels; P_1, P_0 – pressure in the pressure line of the valve and ambient pressure; p_{kl} – valve debugging pressure.

Equation of fluid flow through the safety valve Q_{k2} (17):

$$Q_{k2} = \begin{cases} 0, p_2 < p_{kl} \\ \mu \cdot F_{k2} \cdot \sqrt{\frac{2}{\rho}} \cdot \sqrt{p_2 - p_0} \cdot sign(p_2 - p_0), p_2 \geq p_{kl} \end{cases} \quad (17)$$

Q_{k2} – fuel consumption through the non-return valve of diesel fuel; $\propto$ – dynamic viscosity of diesel fuel; F_{k2} – the cross-sectional area of the valve; P_2, P_0 – pressure in the pressure line of the valve and ambient pressure; p_{kl} – valve debugging pressure.

Cost balance equation in the biofuel line (18):

$$Q_{d2} = \mu \cdot F_{d2}(U_2) \cdot \sqrt{\frac{2}{\rho_{BF}}} \cdot \sqrt{P_2 - P_4} \cdot sign(P_2 - P_4) \quad (18)$$

Q_{d2} – fuel consumption through the biofuel throttle; $\propto$ – dynamic viscosity of biofuels; F_{d2} – the cross-sectional area of the throttle; ρ_{BF} – density of biofuels; P_2, P_4 – pressure before and after the throttle.

Consumption at the entrance to the diesel fuel mixer (19):

$$Q_{zm1} = \mu \cdot F_{zm1} \cdot \sqrt{\frac{2}{\rho_{DF}}} \cdot \sqrt{P_3 - P_5} \cdot sign(P_3 - P_5) \quad (19)$$

Q_{zm1} – consumption at the entrance to the diesel fuel mixer; $\propto$ – dynamic viscosity of diesel fuel; F_{zm1} – the cross-sectional area of the inlet of diesel fuel; P_3, P_5 – pressure before and after the mixer.

Consumption at the entrance to the biofuel mixer (20):

$$Q_{zm2} = \mu \cdot F_{zm2} \cdot \sqrt{\frac{2}{\rho_{BF}}} \cdot \sqrt{P_4 - P_5} \cdot sign(P_4 - P_5) \quad (20)$$

Q_{zm2} – consumption at the entrance to the biofuel mixer; μ – dynamic viscosity of biofuels; F_{zm2} – the cross-sectional area of the biofuel inlet; – density of diesel fuel; P_4, P_5 – pressure before and after the mixer.

ρ_{BF}Writing equation (10) – (14) in the form of Cauchy, taking into account equations (15) – (21), we obtain the following system of equations. Speed of change of pressure on a site from the pump to a throttle of diesel fuel (21):

$$\frac{dp_1}{dt} = \frac{1}{K_1 W_1}\left(q_{н1} \cdot n_{н1} \cdot \eta_{об1} - \mu \cdot F_{d1}\left(U_2\right)\sqrt{\frac{2}{\rho_{ДП}}} \cdot \sqrt{\left|p_1 - p_3\right|} \cdot sign\left(p_1 - p_3\right) - \right.$$
$$\left. -\sigma_1 \cdot p_1 - \begin{vmatrix} 0, p_1 < p_{kl} \\ \mu \cdot F_{k1} \cdot \sqrt{\frac{2}{\rho}} \cdot \sqrt{p_1 - p_0} \cdot sign\left(p_1 - p_0\right), p_1 \geq p_{kl} \end{vmatrix} \right) \tag{21}$$

The rate of change of pressure in the area from the pump to the biofuel throttle (22):

$$\frac{dp_2}{dt} = \frac{1}{K_2 W_2}\left(q_{н2} \cdot n_{н2} \cdot \eta_{об2} - \mu \cdot F_{d12}\left(U_1\right)\sqrt{\frac{2}{\rho_{ДП}}} \cdot \sqrt{\left|p_2 - p_4\right|} \cdot sign\left(p_2 - p_4\right) - \right.$$
$$\left. -\sigma_1 \cdot p_2 - \begin{vmatrix} 0, p_2 < p_{kl} \\ \mu \cdot F_{k2} \cdot \sqrt{\frac{2}{\rho}} \cdot \sqrt{\left|p_2 - p_0\right|} \cdot sign\left(p_2 - p_0\right), p_2 \geq p_{kl} \end{vmatrix} \right) \tag{22}$$

Speed of pressure change in the section from the throttle to the mixer in the diesel fuel line (23):

$$\frac{dp_3}{dt} = \frac{1}{K_3 W_3}\left(\mu \cdot F_{d1}\left(U_2\right)\sqrt{\frac{2}{\rho_{ДП}}} \cdot \sqrt{\left|p_1 - p_3\right|} \cdot sign\left(p_1 - p_3\right) - \right.$$
$$\left. -\mu \cdot F_{zm1}\sqrt{\frac{2}{\rho_{ДП}}} \cdot \sqrt{\left|p_3 - p_5\right|} \cdot sign\left(p_3 - p_5\right) - \sigma_3 \cdot p_3 \right) \tag{23}$$

The rate of change of pressure in the area from the throttle to the mixer in the biofuel line (24):

$$\frac{dp_4}{dt} = \frac{1}{K_4 W_4}\left(\mu \cdot F_{d2}\left(U_2\right)\sqrt{\frac{2}{\rho_{ДП}}} \cdot \sqrt{\left|p_2 - p_4\right|} \cdot sign\left(p_2 - p_4\right) - \right.$$
$$\left. \mu \cdot F_{zm2}\sqrt{\frac{2}{\rho_{ДП}}} \cdot \sqrt{\left|p_4 - p_5\right|} \cdot sign\left(p_4 - p_5\right) - \sigma_4 \cdot p_4 \right) \tag{24}$$

Speed of change of pressure after the mixer in the line of mixed fuel (25):

$$\frac{dp_5}{dt} = \frac{1}{K_5 W_5}\left(\mu \cdot F_{zm}\sqrt{\frac{2}{\rho_{зм}}} \cdot \sqrt{|p_5 - p_в|} \cdot sign(p_5 - p_в) - \sigma_5 \cdot p_5 - \right.$$
$$\left. -\mu \cdot F_{zm1}\sqrt{\frac{2}{\rho_{ДП}}} \cdot \sqrt{|p_3 - p_5|} \cdot sign(p_3 - p_5) - \mu \cdot F_{zm2}\sqrt{\frac{2}{\rho_{ДП}}} \cdot \sqrt{|p_4 - p_5|} \cdot sign(p_4 - p_5)\right) \quad (25)$$

The dependence of the opening of the throttle valve on the voltage will look like (26):

$$F_{d1} = f(U_2); F_{d2} = f(U_1); U_1 = \left(1/U_2 \right); \quad (26)$$

Voltage indices directly depend on the characteristics of the motor, hence (27):

$$U_2 = f\begin{pmatrix} N_e \\ n \\ M_e \\ G_c \\ g_e \end{pmatrix} \quad (27)$$

From equation (27) we find the indicators of the engine and the machine-unit taking into account the work on the fuel mixture.

3.3 Substantiation of design parameters of the fuel mixer of the machine unit

According to the requirements, one of the types of motor fuel for agricultural tractors is diesel blended fuel (DSP), which requires the least constructive adaptation of the engine and has slight deviations of physical and calorific value from the corresponding properties of mineral diesel fuel (DP). The most expedient, for technical and economic reasons, is the preparation of particleboard directly in the engine power supply during the operation of the tractor unit. To do this, a fuel mixer with two inlet and one outlet channel is installed in the low pressure fuel system of the diesel engine (PNVT). The inlet channels are connected by fuel pipelines with tanks of mineral DP and vegetable oil, the output channel – with a fuel pump (PN) [25].

The presence of pipelines of considerable length in PNVT, having different cross-sections, causes the appearance of flows directed across the main flow of fluid and the creation of vortices, which contribute to the intensive mixing of fluid. Therefore, the main purpose of the mixer is to comply with the specified concentration of components in the process of preparation of particleboard and its primary mixing. This simplifies the design of the mixer and provides the required speed of movement of the components in the preparation of particleboard.

The basis of the filter-mixer is the task of creating a stable operation of the power unit using alternative fuels (biofuels) without loss of power, using a redesigned filter for fine cleaning of the engine D-240 (Figure 9).

The device consists of a housing 1, glass 2, insert 3, gasket 4, cover 5, bearings 6, holes for sensor 7, rotor Savonius 8, temperature sensor mixture 9, drain plug 10. When passing biofuel from the fuel tank to the high pressure fuel pump it passes through a filter-mixer, in which it is subjected to thermal forcing, mixing and cleaning. The process of cleaning and thermoforcing is based on the principle of operation of the Savonius rotor. The supply of diesel fuel is at an angle to the rotor, the result of the applied force of the fluid on the rotor is the acceleration of rotation created by the supply of biofuel through the holes in the rotor blades perpendicular to its axis. Due to the operation of the rotor there are centrifugal forces, which in combination with gravity allow to sell fuel through the filter element installed between the insert 3 and the glass 2. Due to the fact that the device is attached directly to the engine also heats the mixture. The temperature sensor installed in the mixer case allows to monitor change of density of mix on earlier found dependences. This provides additional purification and improvement of physicochemical properties of biodiesel.

Mechanical mixing in terms of hydrodynamics is the analysis and solution of the problem (fluid flow around the solid). With the slow movement of the body in a liquid having a high viscosity in its layer adjacent to the surface of this body, a thin boundary layer is formed. Its shape and thickness depend on the shape and size of the body, speed of movement, as well as the density and viscosity of the fluid. At high speeds of the body there is a separation of the boundary layer from the surface of the body, primarily from its edges, moving at the highest speed. A turbulent trail is formed behind the body, and the resistance to movement increases sharply.

When rotating a mechanical stirrer, the greatest speed is observed on its periphery (speed is proportional to the radius of rotation). According to the Bernoulli equation in the peripheral zone, compared with the central,

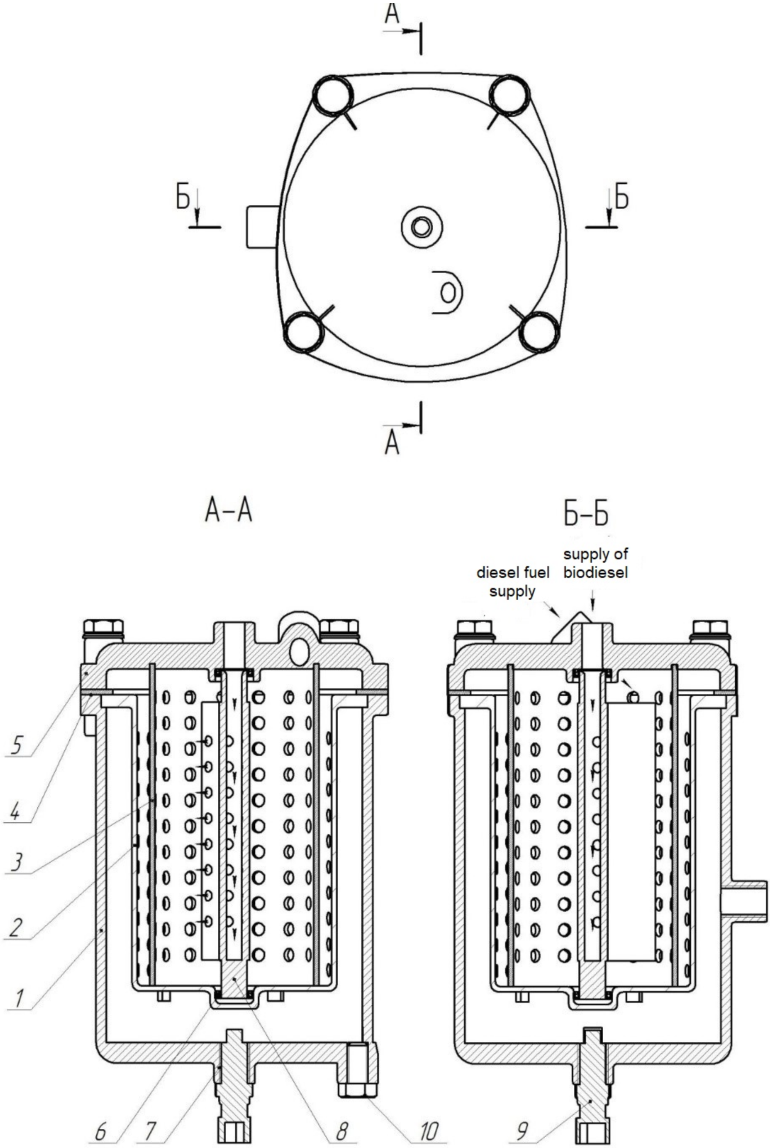

Figure 9. General view of the filter-mixer

a region of reduced static pressure is formed. Under the action of pressure changes, as well as centrifugal forces arising during rotation, the fluid is directed from the center to the periphery.

As a result, there are radial jets of liquid, which cause its intensive mixing. However, it is extremely difficult to describe such a fluid motion mathematically, so we use the Reynolds test to describe the hydrodynamics of mixing. The use of mixing devices is widespread in mechanical engineering not only in manufacturing but also in operation. Modern internal combustion engines can run on an increasing variety of alternative energy sources, one of which is vegetable oils (biofuels), but the power supply systems of such units often need to improve and modernize the design.

An important value to be calculated is the power consumed for mixing *N, W.* This power is proportional to the pressure drop at the front and rear of the stirrer ΔP, PA, the area of distributed pressure S, m^2 and the angular velocity $W_{кут}$, m/s, found in formula (28):

$$W_{ang} = \pi d_m n = d_m n, \qquad (28)$$

$$N = \Delta PS(nd) \qquad (29)$$

n – stirrer speed, rpm; d – stirrer diameter, m

The area of force distribution is proportional to the diameter squared ($S = d^2$). Therefore, the pressure drop is determined by the dependence (30):

$$\Delta P = \frac{N}{nd^3} \qquad (30)$$

For further calculations we use a modified (for mixers) Reynolds test Re_m.

$$\mathrm{Re}_M = \frac{d_m W_{ang} \rho}{\mu} = \frac{n d_m^2 \rho}{\mu}. \qquad (31)$$

When performing calculations it is necessary to take into account the physical and mechanical properties of fuels and their mixtures and design features of the mixer. Using expressions (28–30) we find the values of hydrodynamic similarity of the mixer filter depending on the dynamic viscosity, density and content of biofuels. Estimated data are given in table 1.

When mixing with mechanical devices, there are two modes: laminar and turbulent. Laminar mode (Re_m<30) – non-intensive mixing in which the liquid smoothly flows around the edges of the stirrer blade, is captured by the blades and rotates with them. In the laminar mode, only that part of the liquid that is directly adjacent to the rotor of the mixer moves (Figure 10).

Table 1

Hydrodynamic similarity data of the filter-mixer depending on the dynamic viscosity, density and biofuel content

Criterion Re_M	Dynamic viscosity at T=323K, Pa s	Density ṕ at T=323K, kg/m³	Biofuel content (B) in diesel fuel (D), %
373357	0.003196	832.2	5B/95D
352713	0.003392	834.4	10B/90D
334325	0.003588	836.6	15B/85D
317841	0.003784	838.8	20B/80D
302981	0.00398	841.0	25B/75D
289516	0.004176	843.2	30B/70D
277259	0.004372	845.4	35B/65D
266053	0.004568	847.6	40B/60D
255769	0.004764	849.8	45B/55D
246298	0.00496	852.0	50B/50D
237547	0.005156	854.2	55B/45D
229437	0.005352	856.4	60B/40D
221900	0.005548	858.6	65B/35D
214877	0.005744	860.8	70B/30D
208318	0.00594	863.0	75B/25D
202178	0.006136	865.2	80B/20D
196418	0.006332	867.4	85B/15D
191004	0.006528	869.6	90B/10D
185905	0.006724	871.8	95B/5D
181096	0.00692	874.ß	100B/0D

As the stirrer speed increases, the resistance of the medium caused by the turbulence of the boundary layer and the formation of a turbulent trace in the space behind the moving blades increases. Forced circulation is formed, which provides three-dimensional fluid flow in the device. Approximately this corresponds to the numbers $Re_m = 10^2 - 10^3$ °C.

In the area of developed turbulence (Re_m>104) there is intense mixing of the fluid. These critical values of the Reynolds test are approximate and depend on the design, size of the rotor and the apparatus as a whole (Figure 11).

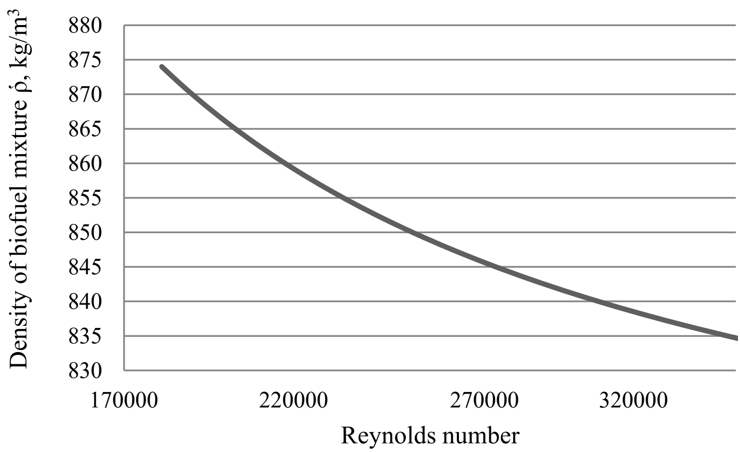

Figure 10. Change in Reynolds number Re_m depending on the density of the biofuel mixture ρ́, kg/m³

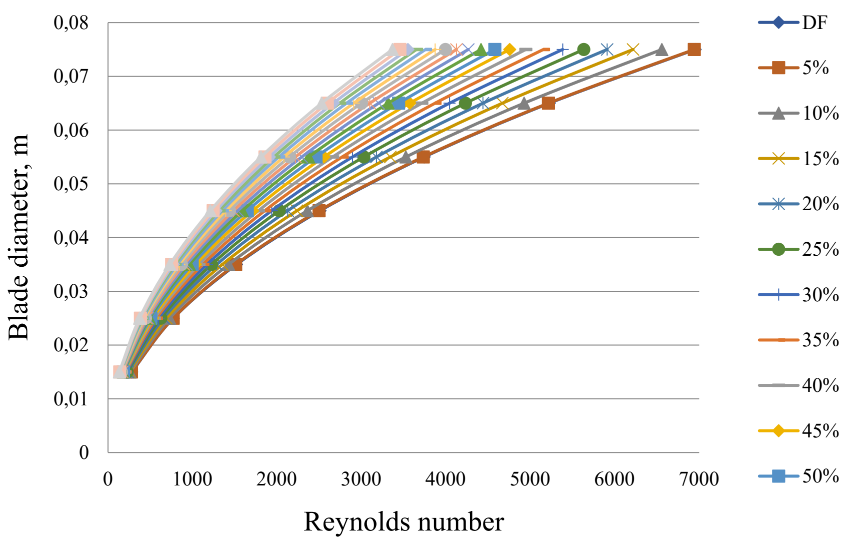

Figure 11. Reynolds number of different types of fuel depending on the diameter of the mixer blade

We optimize the design parameters of the mixer when changing the size of the blade (diameter) from 0.015 m to 0.075 m. Since the device itself is based on the fine filter of the D-240 engine, the main optimization parameter is the geometric dimensions of the Savonius rotor, namely the diameter of the blade, which is taken into account in the calculations and significantly affects the mixer. The Reynolds number was chosen as the main indicator of efficiency.

Analyzing the obtained graphs, we can say that the area of developed turbulence (Re_M>104) is achieved with a blade diameter of 0.015 m, but to increase efficiency, smoothness and intensive mixing is the most structurally appropriate diameter of 0.055 m. design features and design data. Increasing the size of the blade (more than 0.075 m) reduces its strength, increases the complexity of manufacture, and most importantly reduces the speed of rotation, resulting in a decrease in the performance of the mixer as a whole.

To confirm the adequacy of the calculations, we perform modeling of the mixing process using the program FlowVision. Using the developed model of the mixer, we model the working cavity of the device, which is filled with liquid, indicating all the outlets, inlets and physico-chemical parameters of the fuel (Figure 12–14).

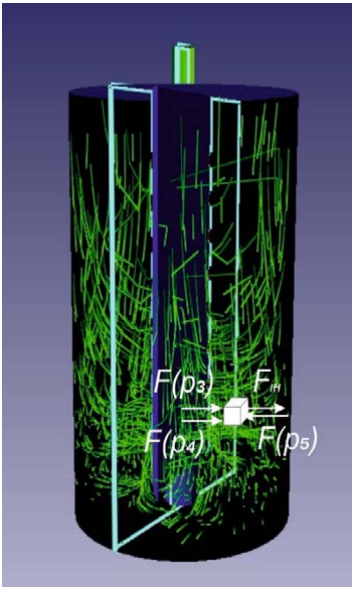

Figure 12. FlowVision simulation of fluid flow in the mixer

As you can see, there is an intense, turbulent mixing of fluid flows, which indicates the adequacy of the calculations. The program also obtained the dependences of the speed and pressure of the working fluid in the mixer on time.

4. Conclusions

1. Analytical review of literature sources on the use of modernized power systems and devices for biofuels and its mixtures showed that it is promising to

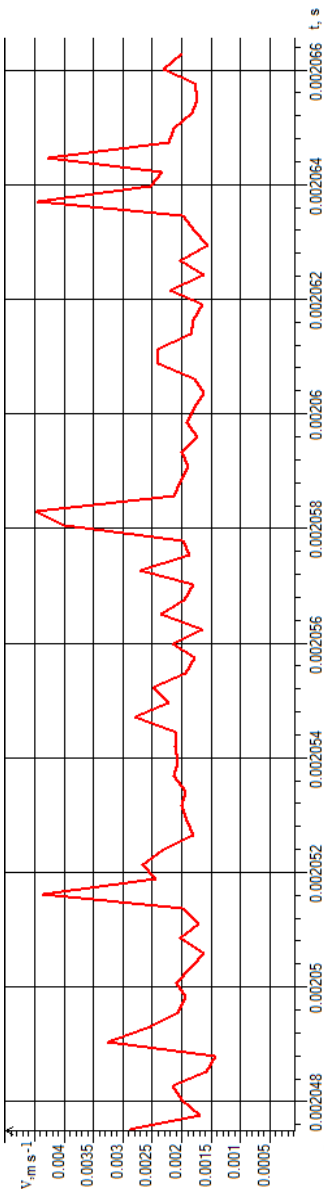

Figure 13. Dependence of the flow rate of liquid particles on time

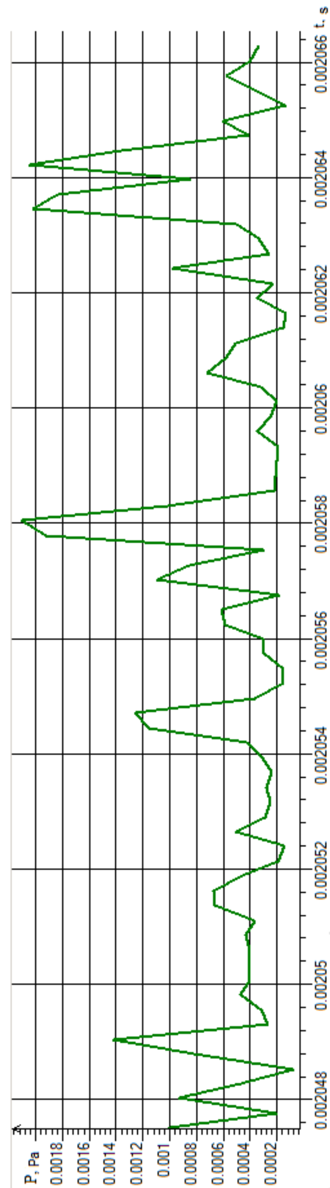

Figure 14. Dependence of fluid pressure differences on time

upgrade and use new equipment and devices, but they require detailed study, analysis, mathematical validity and development of appropriate regulation depending from loading and speed modes of operation of machine units. Analysis of known devices for the creation of blended fuels showed the feasibility of their use. Most of the developed mixers allow to provide effective work of the diesel engine. The main disadvantages are the complexity of the design, significant cost and the inability to adjust the composition of the mixture depending on the load-speed characteristics.

2. A method for calculating the continuity of working fluid flows in the characteristic areas of the advanced power supply system with the definition of the flow Q and pressure P in all key parts of the system and the relationship with the effective performance of the engine.

The technique of construction of the external speed characteristic which is from the indicator diagram and influences effective indicators W, N_e, G_e, g_e of the engine taking into account the factor of mix α is developed. Criteria for optimizing the operation of the machine unit from the biofuel content are determined.

3. The algorithm of functioning of the machine-tractor unit with use of mixed fuel for maintenance of effective work taking into account loading and speed characteristics and operating modes is developed.

4. Checking the adequacy of the mathematical model confirms the experimental studies with an error of up to 3% With increasing biofuel content there is a deterioration of technical and economic indicators. It was found that with a biofuel content of 30%, engine performance does not deteriorate when changing the load and operating modes.

5. The value of ΔS is determined, ie the difference between the opening of the supply chokes DP and BP, which corresponds to the required percentage. This indicator affects the technical and economic performance of the engine, increasing the content of vegetable fuel causes an increase in specific fuel consumption, so when $\Delta S = 0{,}5$ мм^2, corresponding to the ratio of 5% DP/95% BP ge = 267 g/(kWh), the torque when working on mixed fuel 5% DP/95% BP is 9.9% less compared to 95% DP/5% BP, and fuel economy when running on blended fuel 5% DP/95% BP is 3.9% less compared to 95% DP/5% BP. Power increases by 10% when the biofuel content is increased to 95%.

6. With the help of the developed methodology and the experiment conducted on it, the interrelation of the factors influencing the work of the AIT was determined.

It is established that the main diagnostic indicators are fuel supply parameters and indicator characteristics. They play a particularly important role in transients or sudden changes in load.

7. Determining the economic feasibility of manufacturing a faucet allowed to determine the cost, which amounted to UAH 56,815.5. Technological cost 38686 hryvnias.

References:

1. Hunko I. V., Pyasetskyy A. A., Burlaka S. A. (2017) Systema palyvopodachi dyzelnoho dvyhuna z elektronnym rehulyuvannyam skladu dozovanoyi palyvnoyi sumishi. *Tekhnika, enerhetyka, transport APK*, no. 2(97), pp. 47–51.

2. Kaletnik H. M. (2010) Biopalyva: efektyvnist yikh vyrobnytstva ta spozhyvannya v APK Ukrayiny: navch. posibnyk. Kyiv: Ahrarna nauka, 327 p.

3. Hunko I. V., Yaroshchuk R. O., Burlaka S. A. (2018) Vybir optymalnoyi metodyky pokrashchennya skladu sumishevoho biopalyva z roslynnykh oliy. *Visnyk Khmelnytskoho natsionalnoho universytetu*, no. 4, pp. 123–127.

4. Melnyk V. M., Voytsekhivska T. Y., Sumer A. R. (2018) Doslidzhennya osnovnykh tekhniko-ekspluatatsiynykh kharakterystyk alternatyvnykh vydiv palyva dlya dyzelnykh DVZ. *Mashynobuduvannya ta transport*, no. 2, pp. 1–13.

5. Hunko I. V., Yelenych A. P., Burlaka S. A. (2018) Otsinka ekolohichnosti naftovoho palyva ta biopalyva z vykorystannyam metodolohiyi povnoho zhyttyevoho tsyklu. *Visnyk Khmelnytskoho natsionalnoho universytetu*, no. 6(267), tom 2, pp. 246–249.

6. Hunko I. V., Halushchak O. O., Burlaka S. A. (2018) Vyznachennya faktoriv vplyvu biopalyva na hlobalni zminy klimatu. *Tekhnika, enerhetyka, transport APK*, no. 3(102), pp. 90–97.

7. Mahmudul H. M., Hagos F. Y., Mamat R., Adam A. A., Ishak W.F.W., Alenezi R. (2017) Production characterization and performance of biodiesel as analternative fuel in diesel engines – A review. *Renewable and Sustainable Energy. Reviews*, 72, 497–509.

8. Halushchak O. O., Burlaka S. A., Halushchak D. O., Malakov O. I. (2019) Obgruntuvannya vplyvu temperatury komponentiv sumishevoho palyva na robotu dvyhuna. *Visnyk mashynobuduvannya ta transportu*, no. 1(9), pp. 38–43.

9. Burlaka S. A., Yavdyk V. V., Yelenych A. P. (2019) Metody doslidzhen ta sposoby otsinky vplyvu palyv z vidnovlyuvanykh resursiv na robotu dyzelnoho dvyhuna. *Visnyk Khmelnytskoho natsionalnoho universytetu*, no. 2(271), pp. 212–220.

10. Malakov O. I., Burlaka S. A., Mykhalova Yu. O. (2019) Matematychne modelyuvannya ta osnovy konstruyuvannya vibratsiynykh zmishuvachiv. *Visnyk Khmelnytskoho natsionalnoho universytetu*, no. 5(277), pp. 30–33.

11. Burlaka S. A. (2020) Rozrobka zmishuvacha biodyzelnoho palyva ta modelyuvannyam protsesu zmishuvannya. *Visnyk mashynobuduvannya ta transportu*, no. 1(11), pp. 11–17.

12. Hunko I. V., Burlaka S. A. (2020) Matematychne modelyuvannya roboty systemy zhyvlennya dyzelnoho dvyhuna pratsyuyuchoho na biopalyvi z droselnym rehulyuvannya skladu palyvnoyi sumishi. *The scientific heritage*, no. 50, pp. 34–38.

13. L. Raslavičius, Ž. Bazaras (2009) The analysis of the motor characteristics of D–RME–E fuel blend during on-field tests. *Transport,* no. 24(3). Vilnius: Vilniaus gedimino technikos universitetas Academia Scientiarum Lithuaniae, pp. 187–191.

14. Burlaka S. A., Tokarchuk O. A. (2021) Removal of technical and economic indicators of the d-240 engine when using biofuels by applying the DIESEL-RK software complex. *Tekhnika, enerhetyka, transport APK*, no. 4(115), pp. 24–34.

15. Polyevoda Yu. A., Burlaka S. A. (2021) Innovatsiyni metody rozdilennya hlitserynomistkoyi syrovyny vid biopalyva. *Tekhnika, enerhetyka, transport APK*, no. 4(115), pp. 109–118.

16. Burlaka S. A., Kravets S. M. (2021) Diagnosis of fuel equipment of diesel engine by removing vybro indicators of fuel supply. *Tekhnika, enerhetyka, transport APK*, no. 34(114), pp. 113–123.

17. Kaletnik H. M., Klymchuk O. V. (2013) Ekolohichna enerhetyka – osnova rozvytku ekonomiky derzhavy. *Zbalansovane pryrodokorystuvannya. Naukovo-praktychnyy zhurnal*, no. 2–3, pp. 14–17.

18. Burlaka S. A. (2022) Alhorytm funktsionuvannya mashynno-traktornoho ahrehatu z vykorystannyam systemy zhyvlennya zi zmishuvachem palyv. *Visnyk Khmelnytskoho natsionalnoho universytetu*, no. 1(305), pp. 140–144.

19. Burlaka S. A., Yaropud V. M., Zdyrko N. H. (2021) Rekomendatsiyi shchodo otsinky ta diahnostuvannya dyzelnoho dvyhuna pry vykorystanni biopalyva. *Visnyk Khmelnytskoho natsionalnoho universytetu*, no. 4(299), pp. 169–174.

20. Poberezhets J., Kupchuk I., Yaropud V., Burlaka S. (2021) Digestibility of nutrients and broiler chicken productivity under the action of probiotic entero-active. *Visnyk Khmelnytskoho natsionalnoho universytetu*, no. 4(299), pp. 182–186.

21. Kupchuk I. M., Solona O. V., Derevenko I. A., Tverdokhlib I. V. (2018) Verification of the mathematical model of the energy consumption drive for vibrating disc crusher. *INMATEH – Agricultural Engineering*, vol. 55, no. 2, pp. 113–120.

22. Gunko I., Hraniak V., Yaropud V., Kupchuk I., Rutkevych V. (2021) Optical sensor of harmful air impurity concentration. *Przegląd Elektrotechniczny*, vol. 97, no. 7, pp. 76–79.

23. Yaropud V., Hunko I., Aliiev E., Kupchuk I. (2021) Justification of the mechatronic system for pigsty microclimate maintenance. *Agraarteadus*, vol. 32, no. 2, pp. 212–218.

24. Rutkevych V., Kupchuk I., Yaropud V., Hraniak V., Burlaka S. (2022) Numerical simulation of the liquid distribution problem by an adaptive flow distributor. *Przegląd Elektrotechniczny*, vol. 98, no. 2, pp. 64–69.

25. Palamarchuk V., Honcharuk I., Telekalo N., Krychkovskyi V., Kupchuk I., Mordvaniuk M. (2021) Modeling of hybrid cultivation technology corn to ensure energy efficiency for sustainable rural development. *Ukrainian Journal of Ecology*, no. 11(7), pp. 204–211.