CHAPTER «AGRICULTURAL SCIENCES»

IMPROVING THE EFFICIENCY OF THE USE OF BIODIESEL FUEL MIXTURES IN THE SYSTEMS OF AUTONOMOUS ENERGY SUPPLY OF AGRICULTURAL ENTERPRISES

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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.

The use of fossil fuels leads to environmental pollution and climate change in general. To ensure energy security and to improve the environmental conditions necessary for the use of alternative energy sources and to determine their potential impact on the climate and our planet. Looking for more in-depth analysis of all aspects of the use of biofuels in order to determine their potential through the use and economic components.

During studies carried out comparing the performance of different fuels. It has been found that the fuel obtained from biomass is advantageous in environmental protection performance in the production process, is absorbed when the biomass in the growth process and the carbon dioxide in operation.

Analyzing the following requirements fuel when executed estimate (European) emission standards (CO, ShNu, NO X) for the test cycle, reduced CO_2 emissions, the minimum consumption of natural resources and energy, and minimal impact on the environment in its life cycle.

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There are theoretical ways to increase the effective capacity of machine units and to determine the impact of this increase on the technical, economic and environmental efficiency of a diesel internal combustion engine. It has been found that the use of biofuels from plant oils can reduce the use of fossil fuels and environmental improvements. However, when using a fuel, wherein the content of the organic component exceeds 50%, i.e. deterioration of technical and economic parameters of the diesel engine. Among the mixed fuel we studied the best technical and economic characteristics of a mixture containing 70% of mineral fuels and biofuels 30% rapeseed oil. Thus, the subject to reach a dosage adjustment of the change of the fuel mixture, depending on the speed of rotation of the crankshaft of the engine the best environmental performance.

1. Introduction

An agroindustrial complex is one of the basic and stable after volumes entering budget of different industries of formings, in which for realization of production processes the considerable volumes of electric power, mine-out with the use of minerals, mainly imported, fuel resources are consumed, that creates a threat for his effective functioning. Global trends in higher prices of traditional fuel resources used to form the part of the agricultural sector enterprises in electricity demand, taking measures to diversify sources of energy and enhancing energy autonomy. First of all, it is necessary due to the fact that most traditional energy resources imported from Russia and Belarus, which pose a threat to energy security in today's reality of these acts of aggression, especially strategically important, the budget sector – agriculture.

Currently, the most common in Ukraine become autonomous system based on fossil fuel supply, which consist of two main parts: a generator and a motor, which may be gasoline, diesel fuel or gas. However, the full use of such systems is limited by the high cost of traditional fuel resources and makes them uneconomical to complete replacement of centralized power, which leads to the development and establishment of an autonomous power supply from alternative energy conversion [1; 5; 6]. That's why more and more use other forms of energy, called alternatives.

In the short term expected demand growth in oil consumption at a constant volume of production, as expected, the recovery of the national economy will be accompanied by a deficiency of oil and oil products, creating preconditions for increased use of other energy sources.

Measures such as upgrading energy systems and ignition engines, improved neutralization of viral hepatitis, improving the quality of heavy fuel oil is not sufficient. Together, these measures should be the selection and use of alternative fuels from renewable raw materials biologically, thereby reducing emissions of harmful substances, not only during working but also at the stage of fuel to similarly reduce dependence on fuel oil origin.

The aim of the study is the full utilization of biofuel prospects and to determine their effect on the technical, economic, environmental and energy efficiency of the internal combustion engine at different loads and speed conditions.

The study was conducted using methods for mathematical modeling of biodiesel and mixtures thereof using DIESEL-RK. Thus, various load modes were experimentally doslidzhennni engine by physical experiment – depending on power tools porivnyalnnya traction performance during various manufacturing operations. Conducted a systematic analysis of the biofuels market in the world with the use of normative and legislative acts on fuel standards.

2. Substantiation of the composition of biofuels and fuel mixtures of different percentages

Biofuels (BF), methyl esters of vegetable oils (MERO), bio-oil, etc. – are environmentally friendly fuels for diesel engines, obtained by chemical treatment of vegetable oil or animal fat, which can serve as an additive to diesel fuel or completely replace it [8–12].

The raw materials for biofuel production are mainly fats, vegetable oils of various plants and algae, animal fats, fish oil and food production waste. The main raw material in the world is vegetable oil. For example, in Europe – rapeseed oil, in the US – soybean, in Canada – rapeseed oil (genetically modified canola oil used to make rapeseed oil with low erucic acid content), in India – stanza, in Indonesia and the Philippines – palm and coconut oil, in Africa – soybeans and jatropha, in Brazil – castor oil [9].

The structure of vegetable oils is almost indistinguishable from each other, differing only in carbon content and saturation of fatty acids.

Since biofuels are obtained mainly from vegetable raw materials, the problem of limiting the area of seeds arises due to the growing needs of the food industry. The Global Petroleum Club studied the average oil production per hectare of sown area according to the type of raw material (Table 1).

Table 1

Production of oil from various raw materials from one hectare of land per year

Raw	The average oil yield per year		Raw	The average oil yield per year	
	kg/ha	l/ha		kg/ha	l/ha
Corn	145	172	Fig	696	828
Cashew	148	176	Sunflower	800	952
Oat	183	217	Cocoa	863	1026
Lupine	195	232	Peanut	890	1059
Calendula	266	305	Poppy	978	1163
Cotton	273	326	Rapeseed	1000	1190
Hemp	305	363	Olive	1019	1212
Soy	375	446	Tick	1188	1413
Coffee	386	459	Pecan	1505	1791
Linen	402	478	Jojoba	1528	1818
Hazelnut	405	482	Jatropha	1590	1892
Pumpkin seeds	449	534	Macadamia	1887	2246
Coriander	450	536	Brazil nut	2010	2392
Mustard seeds	481	572	Avocado	2217	2638
Saffron seeds	490	583	Coconut	2260	2689
Sesame	585	696	Oil palm	5000	5950
Safflower	655	779	Algae		95000

Given the differences in the production and evaluation methods of biofuel mixtures, attention is focused on the quality of biofuels used for the manufacture of finished mixtures [7]. Existing guidelines for manufacturers producing and using 100% biofuels (B100) and petroleum-based SOs to produce a 5% biofuel blend (B5) indicate that the fuel should comply with WWFC recommendations for different categories of fuel markets, as well as conventional SOEs.

The use of biofuels is an important factor in increasing the supply of diesel fuel. As renewable fuels, they have the potential to reduce greenhouse gas emissions. Proper formulation can also help ensure lower emissions of common pollutants. The key to achieving low emissions is the production of good quality raw materials, as well as the mixing and sale of finished fuel in a way that preserves its quality to the final consumer [9].

Biofuels are of particular interest today because of their potential to reduce the use of petroleum-based fuels, increase energy security and reduce greenhouse gas emissions. Rapeseed oil-based biofuels are one of the fuels already in use, and there are other promising fuels, such as hydrotreated vegetable oils (HBO) and biomass-derived fuels (BTL). The quality of biofuels is an important indicator for its use.

[10] provides recommendations for manufacturers regarding the quality of biofuels required for use in engines.

Ready-made biofuel mixtures must meet the requirements established by the documentation for the relevant category of diesel fuel.

Biofuels are characterized by a change in quality over time. From the moment of production oxidation reactions begin in it. Air temperature, as well as water and oxygen contained in it, affect the rate of oxidation. Antioxidant additives can help slow down this deterioration process and to some extent improve fuel stability [10]. Their effectiveness depends on whether they are added during the production of biofuels, or immediately after its completion. Excessive use of antioxidants can lead to additional sludge formation. Therefore, care must be taken when choosing the type and amount of antioxidants. It is not recommended to store ready mixes for a long time (more than 30 days) or in adverse conditions (high humidity and temperature) [11].

Biofuels and their mixtures must have homogeneous properties to ensure proper quality both before and after mixing. High-speed injection, mixing – better spraying, as it ensures higher fuel quality.

The content of ether (not less than 96.5%) in the fuel shows the amount of fatty acid methyl ester (FAME) – this is an indicator of fuel quality. Low levels can mean that chemical compounds such as triglycerides used in the production process, catalysts (KOH / NaOH) or methanol remain in the fuel. A low level may also indicate contamination of FAME with other compounds. These impurities can cause clogging of the fuel filter, deposits in the engine and other problems. States may legislate for the ether (biocomponent) content of fuels.

This standard applies to fatty acid methyl esters (FAME), at their 100% concentration, used as biofuels for diesel engines or fuel components that meet the requirements of the standard. Fuels prepared solely on the basis of fatty acid methyl esters (FAME) are intended for vehicles with diesel engines designed or converted to run on this type of fuel.

In the Table 2 shows the European standard EN 14214: 2003 for biofuels, the National Standard of Ukraine for biofuels DSTU 6081: 2009 and DSTU 7688: 2015 – for diesel fuel.

Oxidation resistance is one of the most important properties because FAME oxidizes faster than petroleum diesel and produces reaction products that can damage the engine. Fuels with a large number of methylene molecules adjacent to the double bond are particularly prone to oxidation [12]. The process begins with the production of vegetable oil and continues until the transesterification reaction.

Oxidation forms peroxides (hydroperoxides), which subsequently react with the formation of acids. Molecules can also polymerize to form resins, precipitates and other insoluble compounds. Unlike peroxides, which usually disappear at some point in the transesterification process, the polymer formed during the oxidation process does not disappear and remains in the mixture.

The acid number is a measure of the acid in the fuel. They come from two sources: (I) acids used in the production of biofuels, which will be completely removed during the production process; (II) acids formed as a by-product in the oxidation process. The value of the acid is measured by the amount of KOH (potassium hydroxide) required to neutralize one gram of FAME. The acid number of biofuels will change over time due to the normal oxidation process and this change is a good indicator of B100 stability. The presence of acid in the fuel can damage the injection system and other metal parts [13].

Cetane number is a measure of ignition quality and combustion characteristic. Fuel with a low cetane number leads to difficult start-up, hard engine operation, increased noise and smoky exhaust gases (Table 3).

Biofuels can be used as additives in the amount of 1-2% for petroleum diesel fuel with extremely low sulfur content. Biofuel blends with diesel

Table 2

Physico-chemical parameters and requirements for biofuels and diesel fuels

Indicator	Dimensionality	National standard of Ukraine for biofuels DSTU 6081: 2009	European standard for biofuels EN 14214: 2003	Standard of Ukraine for diesel fuel DSTU 7688: 2015	
		Value	Value	Value	
1	2	3	4	5	6
The content of ethers	% (m/m)	96.5	96.5	-	-
Density for temperatures 15 °C	kg/m^3	860-900	860-900	860	840
Kinematic viscosity at a temperature of 40 °C	mg/s	3.5-5.0	3.5-5.0	3.0 – 6.0	1.8-6.0
Flash point in a closed crucible, not less than	°C	120	120	40-62	35-40
Mass fraction of sulfur, not more than	mg/kg	10	10	0.05-0.20	0.05-0.20
Coke content of 10% of the distillation residue, not more than	% (m/m)	0.3	0.3	0.30	0.30
Cetane number, not less than		51	51	45	45
Ash content, no more than	% (m/m)	0.02	0.02	0.01	0.01
Water content, not more than	mg/kg	500	500	-	-
The content of mechanical impurities, not more than	mg/kg	24	24	-	-
Copper plate test (3 hours at 50 ° C)	rating	class 1	class 1	withstands	withstands
Oxidative stability, 110 ° C, not less than	hours	6.0	6.0	-	-
Acid number, not more than	mg KOH/g	0.50	0.50	5	5

(End of Table 2)

Indicator	Dimensionality	National standard of Ukraine for biofuels DSTU 6081: 2009	European standard for biofuels EN 14214: 2003	Standard of Ukraine for diesel fuel DSTU 7688: 2015	
		Value	Value	Value	
1	**2**	**3**	**4**	**5**	**6**
Iodine number, not more than	гJ2/100	120	120	6	6
Linolenic acid methyl esters, not more than	% (m/m)	12.0	12.0	-	-
Polyunsaturated (> 4 = double bonds) methyl esters	% (m/m)	1	1	-	-
Methanol content, not more than	% (m/m)	0.20	0.20	-	-
Monoglyceride content, not more than	% (m/m)	0.80	0.80	-	-
Diglyceride content, not more than	% (m/m)	0.20	0.20	-	-
Triglyceride content, not more than	% (m/m)	0.20	0.20	-	-
Free glycerin, no more than	% (m/m)	0.02	0.02	-	-
Total glycerin, no more than	% (m / m)	0.26	0.26	-	-
1st group of alkali metals (Na + K), not more than	mg/kg	5.0	5.0	-	-
2nd group of alkali metals (Ca + Mg), not more than	mg/kg	5.0	5.0	-	-
Phosphorus content, not more than	mg/kg	10.0	10.0	-	-

Table 3

Physico-chemical properties of biofuels and mixtures

Physico-chemical properties	Mixtures of diesel fuel and rapeseed oil derivatives							
	Clean DF	0.7 DF+ 0.3 RO	0.5 DF+ 0.5 RO	0.3 DF+0.7 RO		Clean RO	MERO	EER0
Density at 20 °C, kg/m^3	830	856	873	890		916	877	895
The viscosity is kinematic, at 20 °C, mm^2/s	3.8	9.3	16.9	31		75	8	32
The heat of combustion is lower	42.5	40.9	39.9	38.9		373	37.8	36.8
N.MJ kg (MJ/l)	(35.3)	(35.0)	(34.8)	(34.6)		(34.2)	(33.2)	(32.9)
Cetane number	45	42	41	22		26	48	-
Autoignition temperature, °C		260	-	-	-	318	230	-
Stoichiometric ratio (air: fuel)		143:1	13.8:1	13.4:1	13.0:1	12.5:1	12.6:1	12.6:1
Content, % wt.:		87.0	84.0	82.0	80.0	77.0	77.5	77.6
carbon		12.6	12.4	12.3	12.2	12.0	12.0	12.0
hydrogen		0.4	3.6	5.7	7.8	11.0	10.5	10.4
Sulfur content, % wt.		0.20	0.14	0.1	0.06	0.002	0.002	
Coking 10%		0.2	-	-	-	0.4	03	0.3
Specific carbon content (Hu), g/MJ		20.5	20.5	20.6	20.6	20.6	20.5	20.5

are denoted by the letter “B”, for example, a blend of 20% biofuels and 80% diesel fuels is B20, which is a common replacement and the most common biofuel blend in the United States used by individual agricultural companies.

With proper preparation of the fuel system of a diesel engine, such as the installation of special heaters, as well as the replacement of materials of seals in contact with the fuel, you can use in the engine and clean biofuel (B100). It has been found that B20 biofuels reduce emissions by five times compared to B100, and a 2% mixture of biofuels can be used as a conventional fuel additive, but, of course, it least improves emissions [14].

When choosing a rational ratio of alternative and diesel fuel, it can be argued that the deterioration of engine power does not cause a mixture of fuels with an alternative fuel content of up to 30%. However, it should also be borne in mind that if the engine is not running at rated power, but is underloaded, then at almost all ratios and operating modes, power decreases, and specific fuel consumption increases by no more than 1-3%. With a significant engine underload of 60% or more, it is possible to perform agricultural operations on the fuel mixture, where the share of alternative varies from 5 to 100% without significant deterioration in productivity.

The main advantages of biofuels.

We emphasize that it has no benzene odor and is made from oils, the raw materials for which are plants that improve the structural and chemical composition of soils in crop rotation systems. Biofuels are biologically harmless compared to mineral, one liter of which can contaminate one million liters of drinking water and lead to the death of aquatic flora and fauna. Biofuels for diesel engines, as experiments show, when in contact with water does not harm plants or animals. In addition, it undergoes almost complete biodegradation (in the soil or water, microorganisms process 99% of biofuels per month), which allows us to talk about minimizing water pollution.

Reduction of CO_2 emissions.

Combustion emits exactly the same amount of carbon dioxide that was consumed from the atmosphere by the plant, which is the raw material for oil production, for the entire period of its life. However, it should be noted that to call biofuels environmentally friendly would be incorrect. It emits less carbon dioxide than conventional fuels. It's no secret that emissions can be minimized with a catalyst that converts hydrocarbons and carbon monoxide into water and carbon dioxide. But it should be noted that the oxide is sensitive to the presence of sulfur in the fuel, which "poisons" the catalyst for a long time and leads to increased emissions of residual particles. Therefore, a special role is played by the fact that biofuels, compared to minerals, contain almost no sulfur (<0.001%).

Mineral fuel loses its lubricating ability when sulfur compounds are removed from it. Biofuels, despite the much lower sulfur content, are characterized by good lubricating properties, which extends the life of the engine. This is due to its chemical composition and oxygen content.

When running a biofuel engine, its moving parts are lubricated at the same time, as a result of which, as tests show, the service life of the engine and fuel pump increases by an average of 60%.

A very important point for organizations involved in the storage and transportation of fuels and lubricants. For biofuels, its value exceeds 150 ° C, which allows us to call biofuels a relatively safe substance. It can be used in all types of diesel engines installed on land and water modes of transport, as well as on stationary diesel installations. Summing up, we can briefly note the following main advantages:

– the use of renewable raw materials to obtain the main component;

– obtaining valuable by-products: solid fuel, cake for feed preparation, technical soap, glycerin;

– pollution of a small amount of wastewater;

– no harmful gaseous emissions;

– use of material- and resource-saving technology for biofuel production.

3. Indicators of physicochemical properties of a mixture of biofuels and diesel fuels

Due to the fact that biofuels from vegetable oils have a higher density, viscosity and surface tension, it complicates its use in the standard engine power supply system. After analyzing the physico-chemical parameters of biofuels made from rapeseed oil, its main indicators were determined in relation to diesel fuel (Figure 1 – Figure 3).

Physico-chemical parameters of biofuels and their mixtures differ from similar indicators of diesel fuel (Table 4).

Table 4

Influence of biofuel content on physicochemical parameters of the mixture

The composition of the mixture, %	Indexes					
	C (carbon)	H (hydrogen)	About (oxygen)	Lower heat of combustion Q_n, MJ/kg	The density of mixtures ρ́ at T = 323K, kg/m³	Dynamic viscosity μ at T = 323K, Pa s
5B/95D	0,865	0,12575	0,00925	42,3475	832,2	0,003196
10B/90D	0,86	0,1255	0,0145	42,195	834,4	0,003392
15B/85D	0,855	0,12525	0,01975	42,0425	836,6	0,003588
20B/80D	0,85	0,125	0,025	41,89	838,8	0,003784
25B/75D	0,845	0,12475	0,03025	41,7375	841	0,00398
30B/70D	0,84	0,1245	0,0355	41,585	843,2	0,004176
35B/65D	0,835	0,12425	0,04075	41,4325	845,4	0,004372
40B/60D	0,83	0,124	0,046	41,28	847,6	0,004568
45B/55D	0,825	0,12375	0,05125	41,1275	849,8	0,004764
50B/50D	0,82	0,1235	0,0565	40,975	852	0,00496
55B/45D	0,815	0,12325	0,06175	40,8225	854,2	0,005156
60B/40D	0,81	0,123	0,067	40,67	856,4	0,005352
65B/35D	0,805	0,12275	0,07225	40,5175	858,6	0,005548
70B/30D	0,8	0,1225	0,0775	40,365	860,8	0,005744
75B/25D	0,795	0,12225	0,08275	40,2125	863	0,00594
80B/20D	0,79	0,122	0,088	40,06	865,2	0,006136
85B/15D	0,785	0,12175	0,09325	39,9075	867,4	0,006332
90B/10D	0,78	0,1215	0,0985	39,755	869,6	0,006528
95B/5D	0,775	0,12125	0,10375	39,6025	871,8	0,006724
100B/0D	0,77	0,121	0,109	39,45	874	0,00692

Among other things, the fuel is not sprayed well enough 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.

The impact of plant fuels on the environmental and economic performance of diesel has been established by domestic and foreign scientists [14–15], indicating a change in the technical and economic performance of the machine-tractor unit from the physical and chemical performance of the fuel.Due to the fact that biofuels contain oxygen-containing substances (O = 10.9%), its lower heat of combustion (Q_n = 39.45 MJ/kg) is less than diesel fuel (Q_n = 42.5 MJ/kg) (O = 0.4 %). This fact leads to a decrease in diesel engine power (up to 25% for rated mode).

Compared to diesel, the specific consumption of biofuels at the rated mode of the engine increased by 17%.

A study of the fuel injection and mixing process shows that the average droplet diameter in the MERO study increases to 20%, which increases

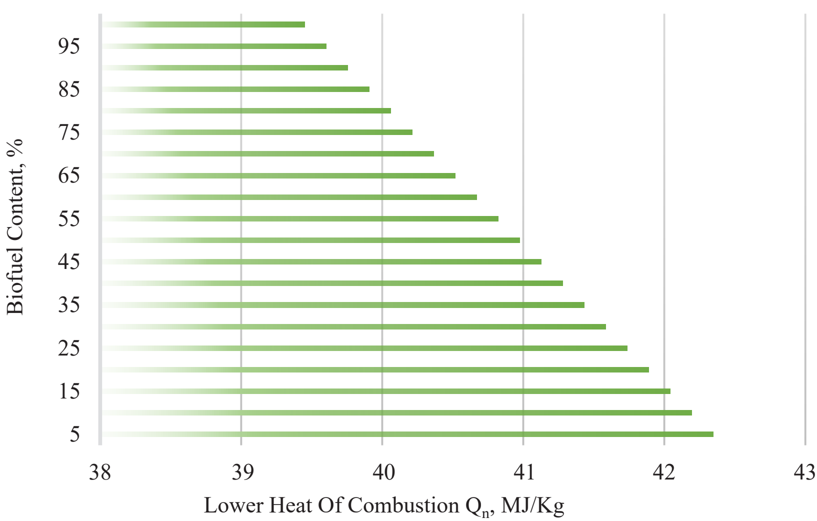

Figure 1. Dependence of lower heat of combustion Q_n, MJ/kg on the content of biofuel, % in diesel fuel

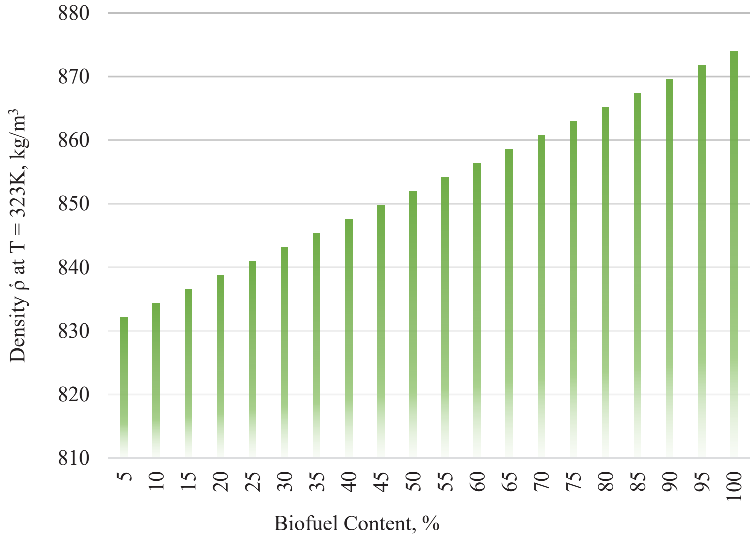

Figure 2. Dependence of density ṗ at T = 323K, kg/m³ on the content of biofuel, % in diesel fuel

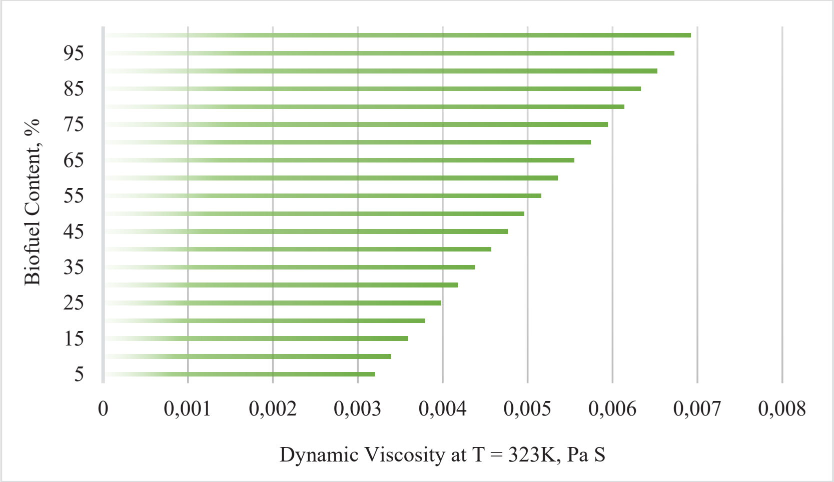

Figure 3. Dependence of dynamic viscosity at T = 323K, Pa·s on the content of biofuel, % in diesel fuel

the jet range compared to diesel fuel and negatively affects the mixing and combustion process.

The use of plant-based alternative fuels with a 10% reduction in carbon content can reduce CO_2 emissions. The rate of soot particles formation during the combustion of biofuels is 8.8 times lower than during the combustion of diesel fuel.

4. Evaluation of the operation of a diesel engine using biofuels and its mixtures of different percentages

Estimation of effective power of the internal combustion engine during application of biofuel and its mixes is carried out with use of factor of mix α, whose values are obtained on the basis of experiments and is calculated by the formula (1):

Dependence of productivity of machine – tractor units on fuel composition (which is characterized by coefficient α) can be determined by exponential dependence (1):

$$W = A\exp(0{,}22\alpha) \quad (1)$$

where A is the empirical coefficient which depends on the composition of the unit. For example, for the unit MTZ-80 + KPS-4 A = 4.0, and for MTZ-80 + KRN-5,6A – A = 5,4.

Similarly, we find the specific hectare of fuel consumption:

$$g_z = A\exp(-0{,}22\alpha) \quad (2)$$

where A is the empirical coefficient, which depends on the composition of the unit. For the unit MTZ-80 + KPS-4 it is equal to A = 0.16, and for MTZ-80 + KRN-5.6A, A = 0.176.

According to this dependence, performing simulations to assess the performance of machine units with different agricultural implements when the engine is running on diesel fuel and fuel mixture, we obtain the dependences (Figure 4-5).

Increasing the biofuel content leads to reduced productivity and increased specific hectare and hourly fuel consumption. Optimization performance of the machine unit are given in Table 5.

Solving the optimization problem, it can be argued that the use of a mixture of fuels can increase the content of biofuel use up to 50% when performing various technological operations with a slight decrease in productivity and increase in specific and hourly nectar fuel consumption.

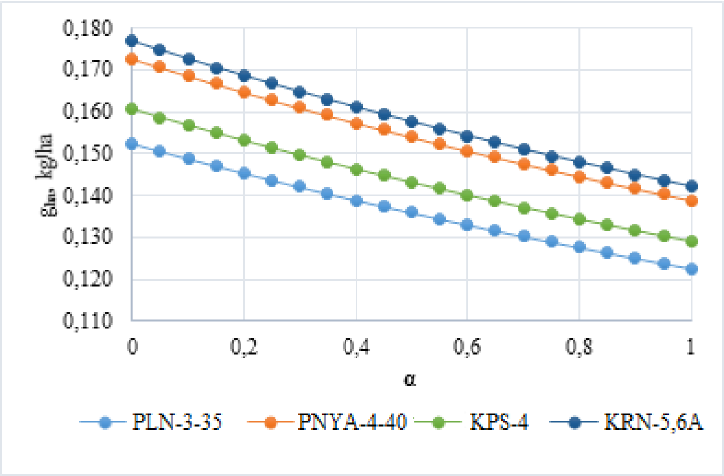

Figure 4. Specific hectare fuel consumption when aggregated with cutting units depending on the biofuel content

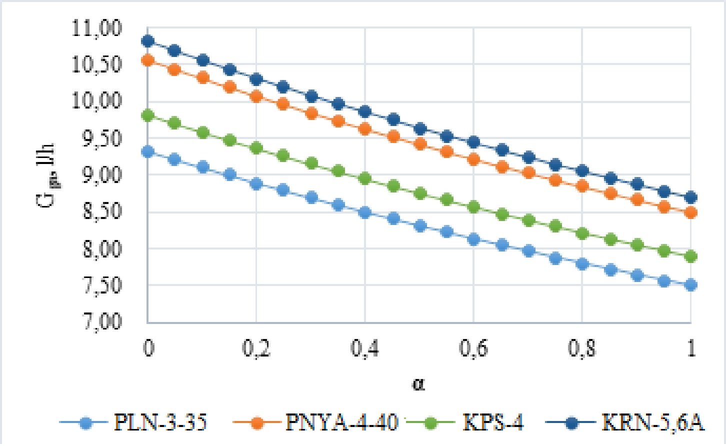

Figure 5. Hourly fuel consumption when aggregating with cutting units depending on the mixing factor

Table 5

Optimization performance of the machine unit using a mixture of fuels

α	Potential productivity W, ha/h				Potential specific hectare fuel consumption g_{ha}, kg/h				Potential hourly fuel consumption G_{ha}, l/h			
	PLN-3-35	PNYA-4-40	KPS-4	KRN-5,6A	PLN-3-35	PNYA-4-40	KPS-4	KRN-5,6A	PLN-3-35	PNYA-4-40	KPS-4	KRN-5,6A
0	0,17	0,11	3,67	6,71	0,123	0,139	0,129	0,142	7,50	8,50	7,90	8,70
0,05	0,17	0,11	3,64	6,64	0,124	0,140	0,130	0,144	7,57	8,58	7,98	8,79
0,1	0,17	0,11	3,60	6,57	0,125	0,142	0,132	0,145	7,65	8,67	8,06	8,87
0,15	0,17	0,11	3,56	6,51	0,126	0,143	0,133	0,146	7,73	8,76	8,14	8,96
0,2	0,16	0,11	3,53	6,44	0,128	0,145	0,134	0,148	7,81	8,85	8,22	9,06
0,25	0,16	0,10	3,49	6,38	0,129	0,146	0,136	0,149	7,89	8,94	8,31	9,15
0,3	0,16	0,10	3,46	6,31	0,130	0,148	0,137	0,151	7,97	9,03	8,39	9,24
0,35	0,16	0,10	3,42	6,25	0,132	0,149	0,139	0,153	8,05	9,13	8,48	9,34
0,4	0,16	0,10	3,38	6,18	0,133	0,151	0,140	0,154	8,14	9,22	8,57	9,44
0,45	0,16	0,10	3,35	6,11	0,134	0,152	0,142	0,156	8,23	9,32	8,66	9,54
0,5	0,15	0,10	3,31	6,05	0,136	0,154	0,143	0,158	8,32	9,42	8,76	9,65
0,55	0,15	0,10	3,28	5,98	0,137	0,156	0,145	0,159	8,41	9,53	8,85	9,75
0,6	0,15	0,10	3,24	5,92	0,139	0,157	0,146	0,161	8,50	9,63	8,95	9,86
0,65	0,15	0,10	3,20	5,85	0,140	0,159	0,148	0,163	8,60	9,74	9,05	9,97
0,7	0,15	0,10	3,17	5,79	0,142	0,161	0,150	0,165	8,69	9,85	9,16	10,08
0,75	0,15	0,09	3,13	5,72	0,144	0,163	0,151	0,167	8,79	9,97	9,26	10,20
0,8	0,14	0,09	3,10	5,65	0,145	0,165	0,153	0,169	8,90	10,08	9,37	10,32
0,85	0,14	0,09	3,06	5,59	0,147	0,167	0,155	0,171	9,00	10,20	9,48	10,44
0,9	0,14	0,09	3,02	5,52	0,149	0,169	0,157	0,173	9,11	10,32	9,59	10,56
0,95	0,14	0,09	2,99	5,46	0,151	0,171	0,159	0,175	9,22	10,45	9,71	10,69
1	0,14	0,09	2,95	5,39	0,152	0,173	0,161	0,177	9,33	10,57	9,83	10,82

5. Discussion of the results of experimental research

Evaluating the performance of a diesel engine running on a fuel coolant of alternative origin, it is possible to make sure that the fuel content has little effect on the efficiency of the engine, but at this time improves the environmental properties. However, increasing the content of biofuels as a fuel component leads to increased toxic emissions of nitrogen oxides.

Experiments with the use of vegetable oil as a diesel fuel, processed after use for cooking, have quite negative results. Mixing unburned fuel with engine oils in the engine is in itself a problem of conventional cars with diesel engines [16]. However, the use as a fuel of vegetable oils that have not been transesterified without improving additives leads to the fact that these oils begin to react with lubricants, forming polymers, the properties of which do not contribute to the normal operation of engines (Figure 6).

In order to develop recommendations and assess the impact of biofuels and biofuel compositions on capacity, economic and environmental indicators, the D-240 engine (4Ch11 / 12.5) is taken as an example. The studies were performed under conditions of regulatory characteristics with crankshaft speeds from 1400 min^{-1} (maximum torque mode) to 2200 min^{-1} (rated power mode) with an interval of 200 min^{-1} and under load characteristics with a load of 80%, 90%, 100% at different crankshaft speeds, as well as in the conditions of idling characteristics with crankshaft speeds from 800 min^{-1} (minimum-stable speed) to 2330 min^{-1} (maximum speed). Indicators of engine power, efficiency and environmental friendliness when working on biofuels and biofuel compositions were compared in similar modes with the corresponding indicators on commercial diesel fuel of petroleum origin.

At all crankshaft speeds at 100% load, the engine produces the most power when running on commercial petroleum diesel fuel and slightly less on biofuel compositions. Moreover, as the percentage of methyl ester of rapeseed oil in blended fuels, this difference increases, but does not exceed 5% (Figure 7).

In nominal mode, the maximum decrease in power and increase in hourly fuel consumption is observed when working on a mixture of B75. At the same time, engine power fell by 3.2% (from 56.1 kW to 54.3 kW), and hourly fuel consumption increased by 8.3% (from 15.02 kg/h to 16.38 kg/h). The smallest decrease in power (by 0.7%) and increase in hourly fuel consumption (by 3%) in nominal mode is observed when running a diesel

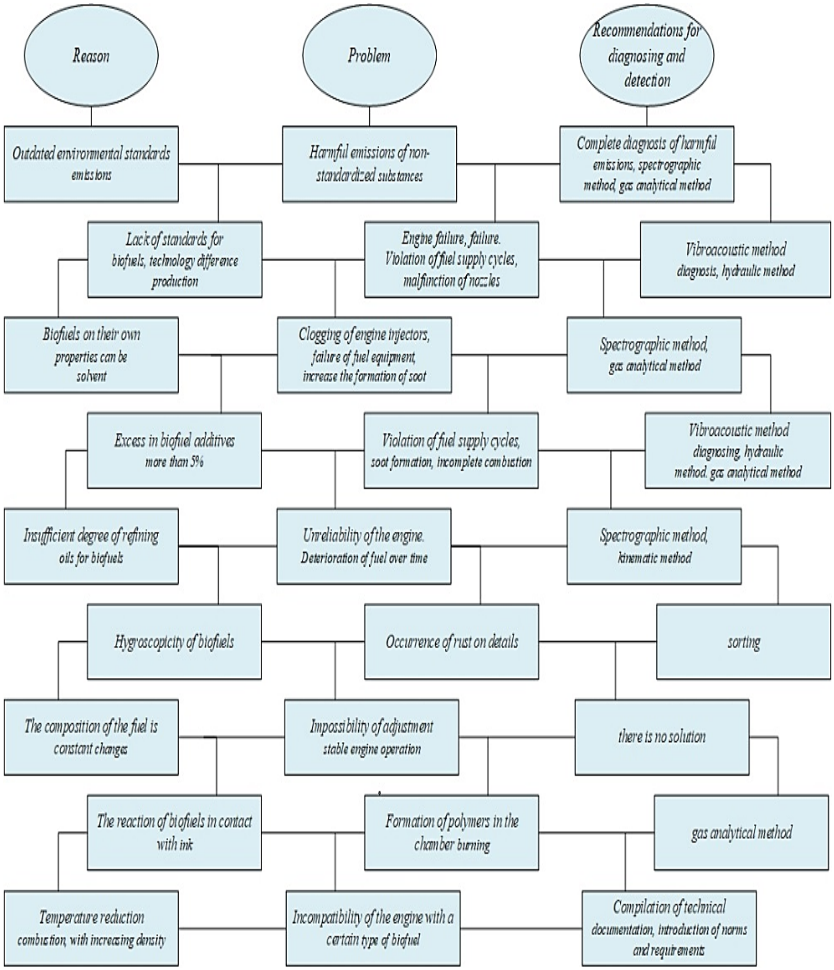

Figure 6. Problems that arise when using biofuels

on mixed fuels B25. Under the conditions of the regulatory characteristics of the diesel engine at 100% load in the frequency range from 1400 min^{-1} to 2200 min^{-1}, the maximum cycle pressure when working on the BF and on all types of biofuels increases.

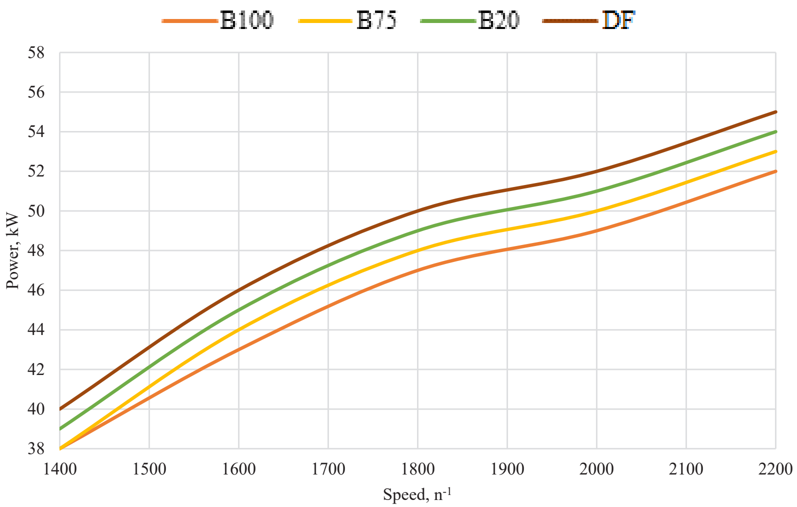

Figure 7. Indicators of effective power of the engine 4Ch11/12,5 (D-240) in the conditions of the regulatory characteristic when working on fuels of various structure

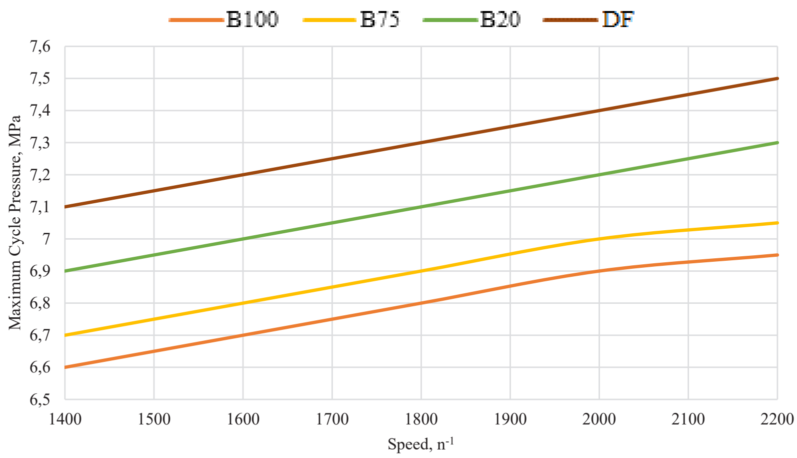

Figure 8. Indicators of the maximum pressure of a cycle of the engine 4Ch11 / 12,5 (D-240) in the conditions of the regulatory characteristic when working on fuels of various structure

However, as the amount of MERO in the blended fuel increases, the maximum cycle pressure decreases. Thus, when working on the BF in the nominal mode, it was 7.54 MPa, on the mixture B25 – 2,292 MPa, on the mixture B75 – 7,108 MPa and on B100 – 7,0 MPa, ie the largest decrease in the maximum cycle pressure was 0.54 MPa (Figure 8).

From the point of view of ecological indicators, the lowest concentration of harmful substances in the exhaust gases on a nominal mode is noted at operation of the engine on B100. Compared with the work on the BF, the concentration of carbon monoxide in the exhaust gases is reduced by 26%, hydrocarbons – by 35%, smoke (soot) – by 14% (Figure 9, 10, 11).

The development of recommendations and the efficiency of the use of biofuels on motor vehicles is proposed to be assessed by a set of indicators at each of the four stages (Figure 12).

At the first stage the assessment of physicochemical and calorific properties of biofuel is performed, the compliance of these properties with petroleum (mineral) diesel fuel is revealed, the type of fuel (rapeseed oil, rapeseed oil methyl ether or mixed fuel) is selected for the engine with split or unseparated chamber shape. initial recommendations (directions) of adaptation for the use of biofuels are given. Currently, for the adaptation of

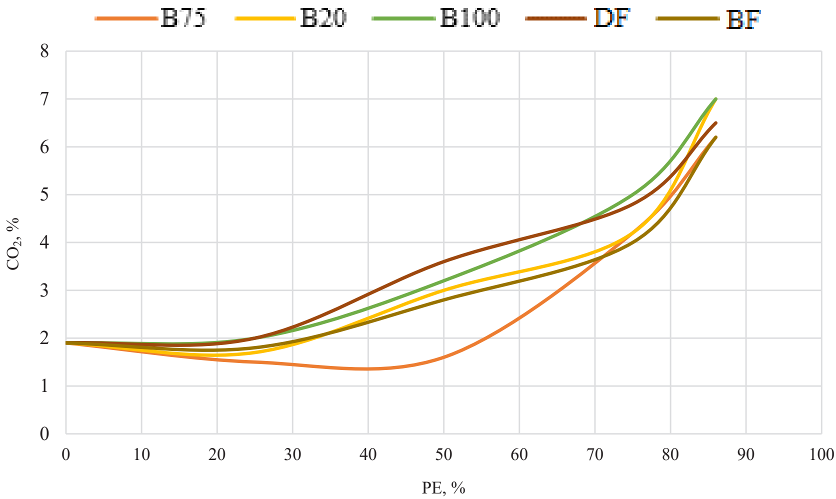

Figure 9. CO_2 emissions in exhaust gases depending on engine power

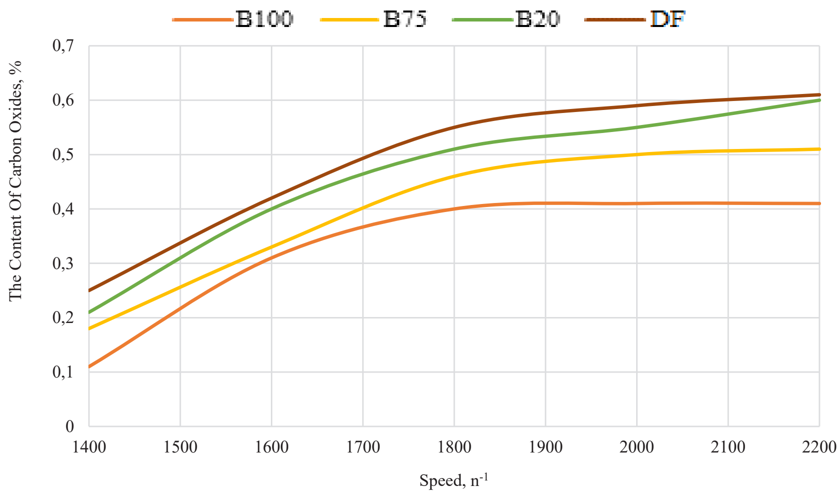

Figure 10. Indicators of the content of carbon oxides of the engine 4Ch11 / 12,5 (D-240) in the conditions of the regulatory characteristic when working on fuels of various structure

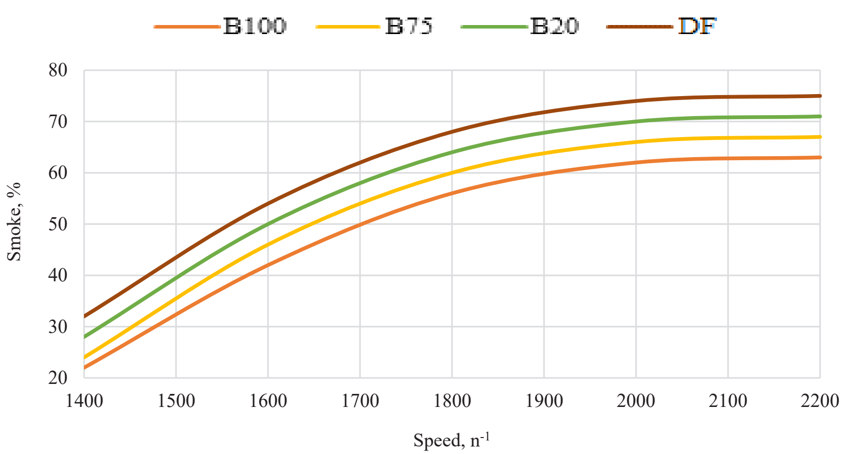

Figure 11. Indicators of smokyness of the 4Ch11 / 12,5 engine (D-240) in the conditions of the regulatory characteristic when working on fuels of various structure

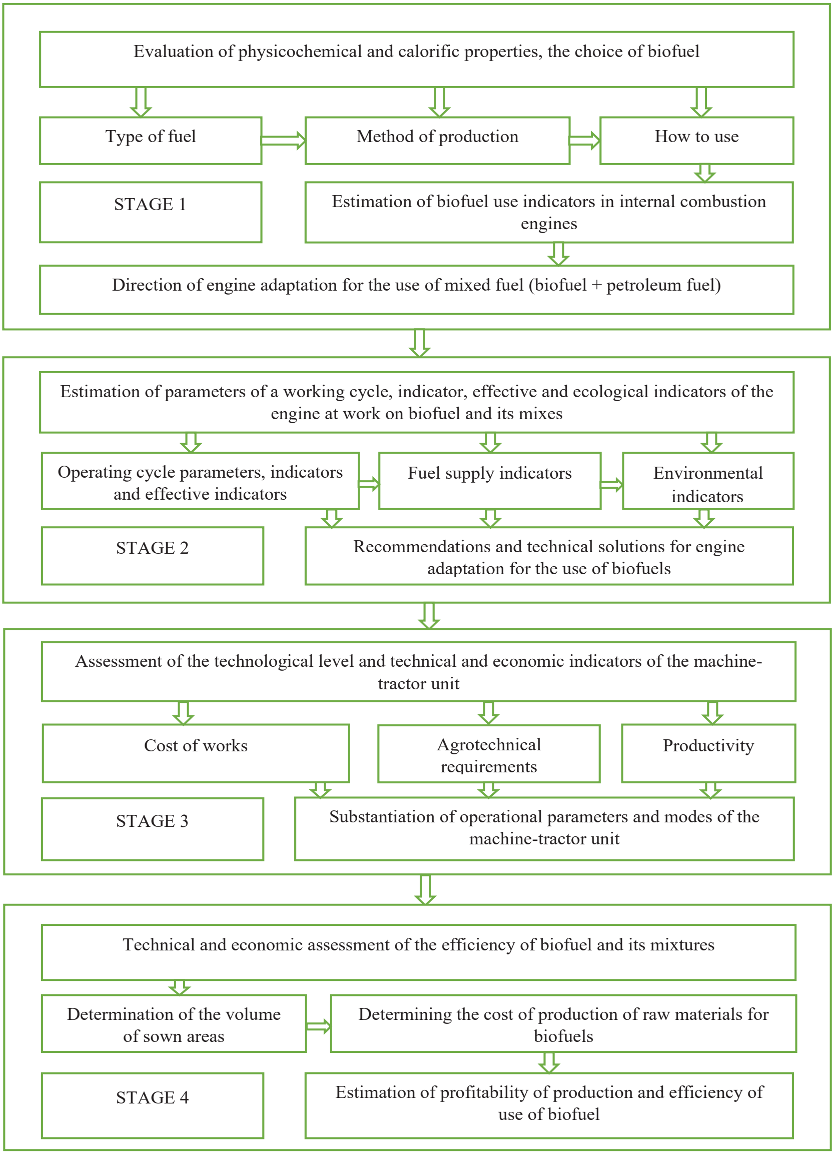

Figure 12. Block diagram of biofuel efficiency indicators

domestic engines for the use of biofuels without significant design changes, the most acceptable alternative fuel is a blended fuel, which is a biofuel composition of petroleum commercial diesel fuel and rapeseed oil (or rapeseed oil methyl ester).

At the second stage the experimental estimation of parameters of supply of fuel and a working cycle, indicator, effective and ecological indicators of the engine is carried out. Thus comparative researches of the fuel equipment on the motorless stand, and also on brake installation at work on oil diesel fuel and various types of mixed fuel are carried out.

As a result of experimental research, the optimal percentage of petroleum and biofuels in the mixture is determined, practical recommendations and technical solutions for constructive adaptation when using a mixed fuel are issued. At the third stage the technological level is estimated and technical and economic indicators of the machine-tractor unit (MTU) in the conditions of operation at work on mixed fuels are defined. Thus the optimum modes of performance of this or that technological process defining structure and working speeds of AIT are established, productivity and cost of works are calculated. Agrotechnical properties of MTU (agrotechnical clearance, protective zone, average specific pressure of engines on the ground, controllability, visibility from the driver's place) practically do not depend on a type of the applied fuel as the main influence on them is made by design features of cars which are a part of MTU.

Biofuels can be used in existing engines and fuel systems without significant negative impact on performance, it is possible to use a standard storage and preparation system, the same as for diesel fuel. Mixtures of biofuel with diesel in small proportions (up to 5%) do not affect the characteristics of the fuel system and engine performance. Upon visual inspection, undissolved water, sludge, suspension and other foreign inclusions must not be visible in the biofuel. Biofuel must be clean, its color can be different, which does not affect its quality [17–19]. Usually its flash point is much higher than the same. This indicates that in the production process all excess methanol was removed from the fuel. The presence of residual methanol, even in small quantities, significantly reduces the flash point, adversely affects fuel pumps, polymers and oil seals, degrades the quality of the combustion process in the engine. At high flash point biofuels are classified as flammable fuels. Water and sediment show the presence in the fuel of unbound water molecules and sediment particles.

The requirements for this characteristic for biofuels are the same as for diesel. Flooding may be the result of improper transportation, storage, or incomplete drying upon receipt. Fuel can begin to oxidize, leading to the formation of sediment. This indicator, together with the viscosity and acid number is a criterion for checking the amount of oxidized fuel during storage. Biofuels have high hygroscopicity and actively absorb moisture, being a favorable environment for the reproduction of microorganisms. This can lead to corrosion of fuel equipment and the formation of deposits of biological origin in the fuel system, as a consequence, to the formation of sludge, clogging of filters and pipelines.

The viscosity of biofuels is slightly higher than mineral, which reduces the flow of fuel in the fuel equipment. It is used mainly in diesel engines, the efficiency of which is determined by the technical condition of fuel equipment. There is evidence that the transition to fuel of vegetable origin with higher viscosity allows to extend the service life of engines even in conditions of extreme wear of the plunger pairs of the fuel pump. At the same time, higher viscosity can lead to deterioration of the combustion process, the formation of soot, splashing fuel when fed into the engine, getting it into the oil to lubricate the engine. Due to the high density and viscosity of biofuels has increased NOx emissions. The increase in the yield of nitrogen oxides during engine operation on the mixture B20 is observed when the engine is running at low speeds and with high load or torque. Prolonged work on biofuels leads to the formation of varnish deposits on fuel injectors, corrosion and jamming of internal components of the fuel injection system, pump failure due to water ingress, sludge and sludge, increased crankcase wear, which reduces the service life of the engine.

The heat of combustion of B100 is slightly lower than that of diesel fuel, so when the engine runs on biofuel, there is a decrease in power. The sulfate residue shows the amount of residual alkaline catalyst, the presence of which in the fuel can lead to deposits in the injector and breakdowns of the fuel system.

The carbon residue is the average of the fuel's ability to form carbon deposits in the engine. For diesel fuel, the carbon residue is determined by distilling 10% of the residue. For biofuels, it is difficult to determine this value for exactly 10% of the residue. Its boiling point is in a wide range. For normal operation of the diesel engine, the fuel must have a cetane number of at least 40.

A higher value provides satisfactory performance of the engine during cold start and reduce the formation of white smoke. The cetane number B100 corresponds to a similar figure for high-quality diesel fuels. Biofuels with a high content of saturated fatty acids may have a cetane number of 70 and above. To calculate the cetane index of the mixture, it is necessary to know the specific gravity and acceleration curves of fuels, the values of which differ for B100 and diesel fuel.

The cloud point for biofuels is higher than for mineral fuels. At low temperatures, the fuel loses mobility, becomes gel-like, begins to crystallize, which leads to clogging of filters, pipelines, difficulty pumping pumps. Some additive manufacturers provide data indicating that when adding additives in the amount of 1% by weight of fuel, the cloud point for B100 is reduced by 12 °C. Other tests show that the chemical treatment of fuels with the addition of additives up to 0.1%, the temperature decreases by 3 °C. Work is underway to create winter types of biofuels by replacing saturated fatty acids with unsaturated ones.

The acid number is an indicator of the presence of free fatty acids in the fuel. The increased content of fatty acids may be due to a violation of the technology of fuel production or indicate the process of decomposition of fuel caused by oxidation. The use of fuel with a high acid number can lead to accelerated formation of deposits in the fuel system and reduce the service life of fuel pumps and filters. Incomplete conversion of fats and oils leads to increased levels of total glycerin, insufficient purification of biofuels causes an increase in the content of free and total glycerin. The high value of these characteristics leads to deposits in the engine, fuel system and tanks, can cause clogging of filters and other problems.

The phosphorus content in B100 should not exceed 0.001%, although in some vegetable oils this value is higher. Phosphorus oils must be pre-cleaned. Its presence can cause failure of catalytic converters of industrial plants for the production of biofuels. The distillation temperature of 90% of the fuel shows whether the fuel will contaminate and interact with high-temperature surfaces and substances (eg lubricant). The boiling point of B100 is higher than on the acceleration curve and is 330...375 °C under normal conditions. Stability of fuel and fuel mixtures is a very important performance indicator. There are two indicators of stability: long-term storage under normal conditions and thermal stability (at elevated values of temperature and (or) pressure, when the fuel circulates in the fuel system of the engine).

Loss of stability of biofuels due to oxidation or prolonged storage can lead to an increase in acid number, viscosity and the formation of resinous deposits and sediments, which leads to clogging of the filters. If these values of the above characteristics do not meet the standards, the use of such fuel is not recommended, it will decompose quickly. B100 with high resistance to oxidation will last longer without changing its basic performance characteristics. Brass, bronze, copper, lead, tin and zinc can accelerate the oxidation of B100, lead to the formation of gel-like insoluble precipitates in contact with some fuel components. The data indicate that B100 has good thermal stability. Saturated vegetable oils and fats can be used for a relatively long time at high temperatures.

B100 can dissolve deposits (even perennials) formed in the fuel system and equipment, fuel tanks. Dissolved deposits cause deterioration of the filtering properties of materials, their swelling and fuel leakage, can clog filters. The cleaning effect depends on the amount of deposits in the system and the concentration when using blended fuels, it increases when using B100 and blends with a biofuel content of more than 35%. Biofuel is a chemically and corrosive liquid. Prolonged contact can soften and decompose natural rubber, nitrile, synthetic rubber, polyethylene, some adhesives and plastics, causing it to seep through seals and hoses. Possible leaks can result in a fuel flare when it hits the engine, a fuel pump failure, and a clogged filter. Materials incompatible with biofuels decompose and crumble.

Biofuels can also dissolve some types of paints and coatings with prolonged contact. Compounds with polypropylene, polyvinyl and polyethylene are highly susceptible to B100. Compounds made of lead, copper, brass, bronze, zinc should be protected from contact with biofuels, so it is necessary to replace equipment from the above materials with equipment and fittings made of stainless and carbon steel or aluminum.

The B20 mixture is compatible with almost all materials. When the engine runs on biofuels, visible smoke, emissions of solid particles, higher hydrocarbons and CO are reduced, which is due to the presence of oxygen in the fuel, which results in more complete combustion of fuel and reduces the number of unburned fuel particles. Biofuels are neutral in terms of CO_2 emissions.

It is released as much during fuel combustion as the plant absorbs during photosynthesis. Only the emission of formaldehyde and nitrogen oxides increases. It is not toxic to living organisms. Tests have shown that in the short term fuel does not pose a threat to humans and animals, there was a slight negative effect on lung tissue at high exposure doses. Biofuels decompose by 90% in 3 weeks in case of leaks or spills, including in contact with water [20–25].

In the table. 6. the basic malfunctions of the diesel engine, the fuel equipment and its systems at work on biofuel are presented.

Some recommendations to determine the conditions that correspond to a high level of stability of biofuels:

– the higher the level of unsaturated compounds, the lower the stability of the fuel; heat and sunlight can accelerate the process, so it is undesirable in the warm season to store fuel under the direct influence of sunlight;

– metals such as copper, brass, bronze, lead, tin and zinc can also increase the speed of the decomposition process and the formation of a significant amount of deposits. B100 should not be stored for a long time in systems containing these materials; additives that bind heavy metals to organic compounds, which mainly consist of biofuels, can reduce or even eliminate the negative impact caused by their presence.

Some recommendations to determine the conditions that correspond to a high level of stability of biofuels (continuation):

– some types of starting components of the transesterification process can wash away natural antioxidants, as a consequence, reduce the stability of the fuel. Brightening, deodorizing, or distilling fats and oils before or during the biofuel production process also results in the removal of natural antioxidants;

– binding of oxygen in the fuel reduces or eliminates the likelihood of oxidation of the fuel and increases the shelf life;

– antioxidants, natural or

– antioxidants, natural or as additives, significantly increase the stability or shelf life of fuel without changing its properties.

Table 6

Possible malfunctions of the diesel engine, fuel equipment and its systems when working on biofuels

Fuel components and characteristics	Action	Malfunction
Fatty acid methyl esters	Causes drying, hardening and destruction of rubber products, ingress into engine oil	Fuel leaks. More frequent engine oil changes
Free methanol	Corrosion of aluminum and zinc	Corrosion of fuel equipment. Low flash point in a closed vessel
Free water in fuel	Converting vegetable oil methyl esters to fatty acids. Corrosion. Increase in electrical conductivity of fuel, development of microorganisms	Clogged filter. Corrosion fuel equipment
Free glycerin	Corrosion of non-ferrous metals. Sludge build-up on moving parts and paintwork	Clogged filters. Clogged fuel injector nozzles
Mono- and diglycerides	Same as the action of glycerin	
Free fatty acids	Electrolyte formation and acceleration of zinc corrosion. Formation of salts of organic acids. Formation of organic compounds	Corrosion of fuel equipment. Clogged filter. Sediment deposition on parts
Increase in fuel density	Increasing injection pressure	Reduction of the resource of fuel equipment
High viscosity at low temperatures	More severe operating conditions of the high-pressure fuel pump (injection pump). Increased wear of parts	Increased wear of the injection pump parts. Deterioration of injection performance fuel. The need to use depressants
Solid particles	Deterioration of the lubricating ability of the fuel	Reduced fuel resource apparatus
Formic and acetic acids	Corrosion of all metal parts	Corrosion of fuel equipment
High molecular weight organic acids	Same as Free Fatty Acids	Corrosion of fuel equipment. Clogged filter. Sediment deposition on parts
Polymerization products	Sediment deposition, especially in mixed fuels	Clogged filter
Phosphorus	Poisoning neutralizers and catalysts of the diesel exhaust system	Failure, decrease in the level of environmental safety of diesel exhaust gases

6. Conclusions

As a result of the analysis of operational indicators it is possible to present some recommendations on its application on engines.

1. Fuel samples should be taken regularly to check its quality and to use biofuels with characteristics corresponding to or close to world standards. Engine manufacturers must provide quality requirements for the B100 used, if used.

2. It is not recommended to store biofuel for a long time under the direct influence of high or low temperatures, the shelf life of fuel mixtures with diesel fuel depends on the concentration of biofuel. Fuel must be stored in clean and dry containers in a dark place. Be sure to remove water from the tanks before filling them. To minimize moisture condensation during storage, keep fuel tanks as full as possible, drain and wash them before and after storing biofuels. Fuel tanks must be airtight to prevent water ingress.

3. It is recommended to regularly clean the drain pipes to prevent corrosion when using mixtures at a biofuel concentration of more than 20%. It is necessary to regularly monitor the water content and the presence of microorganisms in the fuel. Modern antimicrobial additives are effective to prevent the reproduction of microorganisms.

4. Fuel should be heated to reduce density and viscosity. Reducing the advance of fuel injection by 5° is recommended to reduce emissions of nitrogen oxides from the flue gases of diesel engines. The NOS emission level decreases when the engine is running at low loads and low torque values.

5. It is recommended to regulate the supply of fuel to the engine during the transition to biofuels in accordance with the recommendations of engine manufacturers. When returning the diesel engine to 100% diesel, it is not recommended to change the engine characteristics to compensate for energy losses. Before starting work on biofuels, it is recommended to regularly monitor the oil level in the engine, increasing the level may indicate crankcase wear and the need to change the oil. Oil samples should be taken regularly to determine its condition in the engine and the rational service life and interval between replacements.

6. It is not recommended to store fabric materials soaked in biofuel for a long time and together. Impregnated fabrics begin to decompose with

the release of heat, which can lead to spontaneous combustion. At low temperatures it is recommended to heat biofuel in tanks, pipelines, filters or to use in the engine its mixes with low concentration of biofuel.

7. When using fuel at low temperatures, additives are required. It should be borne in mind that standard additives that reduce the pour point of fuels of petroleum origin are not always suitable for biofuels. B100 should be stored at a temperature 3...6 °C above the cloud point. It is possible to store a DB and at a temperature of 4,5...7 °C, depending on initial raw materials this value can be higher.

8. Fuel tanks must be insulated or heated. When running the engine on a mixture of fuels to obtain a stable and homogeneous fuel component, it is recommended to use the method of flow homogenization. The use of biofuels in small quantities (up to 2%) as a mineral additive with low (0.5%) and ultra-low (0.05%) sulfur content improves its lubricating properties, as a result, reduces the wear of fuel equipment.

9. Data on the use of B100 in vehicles show that it can be stored for 2... 4 months without losing stability. ASTM data show that with a minimum stability of B100 can be stored for up to 8 months, the maximum – a year or more. It is indicated that the week of storage of fuel at a temperature of 43 ºC is equivalent to a month of storage at a temperature of 21 °C. On average, it is recommended to store B100 up to 6 months.

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