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IMPROVING ENVIRONMENTAL INDICATORS OF THE WHEELED TRACTOR DIESEL ENGINE BY USING BIOFUELS

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The object of this study is the process of operation of a diesel engine in a wheeled tractor on methyl ether of spent frying sunflower oil. The task being solved is to improve the environmental performance of a diesel engine in a wheeled tractor during the operation of its diesel on such biodiesel fuel and its mixtures with mineral diesel fuel. The characteristics of the diesel D-243 were determined by the experimental method with the measurement of the toxicity of the waste gases during its operation on the methyl ether of the spent sunflower oil, mineral fuel, and their mixtures. A decrease in the content of soot in diesel exhaust gases and a slight increase in the types of nitrogen oxides was registered. The theoretical method using a mathematical model determined the indicators of a wheeled tractor during its movement with a trailer for the accepted driving cycle and the operation of its diesel on different fuels. To that end, the characteristics of a specific diesel engine were described by polynomial models. The adequacy of the mathematical model of the movement of a tractor with a trailer over a driving cycle was tested. By means of a mathematical model, the total road emissions of harmful substances of a diesel engine were calculated when the tractor is running with a trailer over the accepted driving cycle. Calculations were performed for two types of fuel: mineral diesel fuel and biodiesel fuel. Biofuel consumption increases by almost 10 % compared to diesel fuel. The total emissions of harmful substances are 1.1 times lower in a diesel engine running on biofuel than when using mineral fuel. The results could be used in the operation of technological transport in the industry and agriculture provided there is a sufficient volume of raw materials for the production of biofuel

Keywords: technological transport, biodiesel fuel, environmental indicators, waste gases, total toxicity

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1. Introduction

There is a large fleet of wheeled vehicles and mobile agricultural machinery with diesel engines that run on diesel fuel (DF) of petroleum origin. However, according to multiple sources, the oil reserves available to our market may last only until 2028, so the cost of DF will continue to rise. In such a situation, the use of alternative fuels (AF) becomes economically justified. In addition, auto-tractor machinery is one of the biggest polluters of the environment. Therefore, the use of AF will make it possible to significantly reduce the harmful emissions (HE) of exhaust gases (EG) from diesel engines and improve the environmental situation in cities and rural settlements [1].

Tractors with trailers can be used as technological transport. This involves their arrival and work in closed premises. After only a few minutes of diesel operation, the maximum permissible sanitary standards for the content of harmful substances in the air exceed the permissible limits. Therefore, improving the environmental performance of technological vehicles is an urgent task.

2. Literature review and problem statement

Alternative biofuels based on vegetable oils are increasingly being used. It was established that the use of biodiesel fuels (BDF) usually does not require changes in the design of the diesel engine. Tests showed an increase in BDF consumption up to 10 %, which is explained by a lower heat of combustion. At the same time, the emissions of EG of some HSs are decreasing [2]. But the cost of vegetable oils has increased significantly recently. This makes the production of biodiesel based on them economically unprofitable. Biodiesel fuels from vegetable oils belong to the first-generation biofuels. Now the transition to the use of second-generation biofuels is emerging [3, 4]. In connection with this, a way out of the situation may be the use of vegetable oils used in culinary production as raw materials for their production. In this case, the cost of biofuel may be lower compared to petroleum diesel fuel.

The authors of works [5, 6] conducted a study on the feasibility of applying used cooking oil as a raw material for obtaining biofuel. Their analysis revealed that the properties of WCO biodiesel are within acceptable limits. This fuel is cheaper than diesel and less harmful to the environment.

The authors of papers [7, 8] assessed the influence of the quality of used vegetable oil on the properties of biodiesel. Their results showed that CO emissions from WCO were slightly higher than from waste oil biodiesel, but NO_x and smoke emissions were similar. They concluded that due to WCO's ability to degrade and not adversely affect engine performance and emissions, WCO can be considered a promising feedstock for sustainable biodiesel production.

The authors of studies [9, 10] investigated the effect of biodiesel from waste vegetable oil on diesel engine emissions. Their results showed a decrease in HC, CO, and PM, but NO_x increased when biodiesel was used.

The authors of works [11, 12] conducted an experiment on diesel using biodiesel obtained from used cooking oil to study the composition of exhaust gases. The results showed that CO and PM emissions were significantly reduced when using biodiesel compared to diesel fuel. In contrast, NO_x emissions increased with biodiesel compared to diesel, which they attributed to biodiesel's higher cetane number, higher oxygen content, and combustion temperature.

Our review of the literature [5–12] shows that a significant number of studies have confirmed the effectiveness and feasibility of using biodiesel fuels from waste vegetable oils as motor fuel. But only studies on the environmental performance of diesel engines with this fuel were conducted. As the emissions of some harmful substances are decreasing, the emissions of other substances are increasing. Therefore, it is not possible to unambiguously assess the impact of the use of biofuels on the environmental friendliness of equipment. Determining environmental indicators over the driving cycle of a tractor with a trailer makes it possible to objectively assess the total toxicity of exhaust gases.

3. The aim and objectives of the study

The purpose of our study is to determine the possibility of using methyl ether of waste oil as motor fuel for auto-tractor machinery. This will make it possible to expand the fuel base of enterprises at the expense of such biofuel and improve the environmental performance of engines:

– to investigate the indicators of biofuel from spent sunflower oil;

– to investigate the performance of a diesel engine when operating on biofuel from spent sunflower oil;

– to estimate the total toxicity of exhaust gases from a diesel engine of a wheeled tractor during its operation on biofuel.

4. The study materials and methods

The object of the research is the operation process of the D-243 diesel engine of a wheeled tractor on the methyl ether of spent deep-fried sunflower oil.

The main hypothesis of the study assumes that the use of biodiesel fuel obtained from waste oil could improve the overall environmental friendliness of the diesel engine of a wheeled tractor. Physicochemical properties of spent methyl ether and its mixtures with mineral fuel were determined according to standard procedures. In particular, kinematic viscosity was determined by the method according to DSTU 33-2003 with a Pitkevich capillary viscometer at a temperature of 20 °C, as well as at other temperatures. A thermostat was used for this purpose.

The comparison of the fuel-economic and environmental indicators of the diesel engine when working on different fuels was carried out according to the experimental load and speed characteristics, which were described by polynomial models for use in the mathematical model. The hourly consumption of fuel, air, and the content of harmful substances (HS) in the exhaust gases (EG) from a diesel engine during operation under an independent idling mode are satisfactorily described by polynomials of the second power depending on the idling speed n_e. The performance of a diesel engine under load modes is described by polynomials depending on n_e and engine torque M_e. Mass emissions of HS were determined by fuel and air consumption and the concentrations of these substances in EG.

The content of harmful substances in EG (carbon monoxide CO, hydrocarbons C_mH_n, nitrogen oxides NO_x, smoke density D) and the hourly fuel consumption of a diesel engine during operation on biofuel and its mixtures with petroleum fuel are described by third-order polynomials of the following form:

$$\begin{aligned} G_f, G_{air}, \mathrm{CO}, \mathrm{C_mH_n}, \mathrm{NO_x}, \mathrm{D} = A_0 - A_1 n_e M_e^2 - \\ - A_2 C_{bdf} M_e^2 - A_3 M_e^3 + A_4 M_e^2 - A_5 n_e C_{bdf} M_e + \\ + A_6 C_{bdf}^2 - A_7 C_{bdf} M_e + A_8 M_e - A_9 n_e M_e + \\ + A_{10} n_e^{\,2} M_e + A_{11} n_e C_{bdf}^2 + A_{12} C_{bdf}^3 + A_{13} C_{bdf}^2 - \\ - A_{14} C_{bdf} - A_{15} n_e C_{bdf} + A_{16} n_e^2 C_{bdf} - \\ - A_{17} n_e + A_{18} n_e^2 - A_{19} n_e^3, \end{aligned} \qquad (1)$$

where C_{bdf} is the content of biodiesel fuel in mixtures with mineral fuel,

A_0, A_1...A_{19} are polynomial coefficients.

The mathematical model of the movement of a wheeled tractor with a trailer over a driving cycle is built taking into account the operation of the tractor with a trailer and the design features of the diesel engine and tractor transmission. The mathematical model of the movement of a passenger car with a gasoline engine over a driving cycle (DC), constructed at the National Transport University [13], is taken as a basis. Mathematical models of the movement of vehicles over DC are systems of differential and algebraic equations that describe the modes of movement of vehicles and the corresponding modes of engine operation. The input parameters in the mathematical models are the equipped mass of the vehicle, the amount and speed of movement of the fuel supply controls, the selected gear, the time of switching gears, the speed of movement, losses in the transmission, road conditions, loading of the vehicle. The output parameters are fuel consumption and emissions of HS from the EG of engines.

The main quantity for the calculation of all modes is the value of the effective torque of the diesel engine, which is calculated by the second power polynomial dependence on the crankshaft rotation frequency and the position of the fuel control lever. During the movement of the tractor, the traction force on the driving wheels is used to overcome the forces of resistance to movement generated by the road, as well as the forces of resistance to accelerated movement. The force of air drag is not taken into account because of the low speeds of the tractor with a trailer. The equation for converting the rotary motion of wheels into the forward motion of the tractor is as follows:

$$\frac{1}{r_d}\cdot\left[M_i\cdot(q_c,n_e)-M_m\right]\cdot U_{tr}\cdot\eta_{tr}=$$
$$=G_v\cdot\psi\pm M_v\cdot\delta\cdot\frac{dV_v}{dt}, \quad (2)$$

where r_d is the dynamic radius of the driving wheels;

M_i – indicator engine torque;

q_c – cyclic fuel supply;

n_e – engine rotation frequency;

M_m – moment of mechanical losses;

U_{tr} – gear ratio of the transmission;

η_{tr} – transmission efficiency;

G_v, M_v – weight and mass of the vehicle, respectively;

V_v – the speed of the vehicle;

ψ – coefficient of road resistance;

δ – coefficient of consideration of rotating masses.

At small values of the angle α of the longitudinal slope of the road surface, the coefficient of road resistance:

$$\psi=f\pm i, \quad (3)$$

where i is the longitudinal slope of the road.

The value of the coefficient f of the rolling resistance of wheels on the surface of the road with high-quality coatings is in the range of f=0.014–0.020.

Coefficient of consideration of rotating masses:

$$\delta=1+\frac{J_e\cdot U_{tr}^2\cdot\eta_{tr}}{M_v\cdot r_d\cdot r_r}+\frac{\sum J_w}{M_v\cdot r_d\cdot r_r}, \quad (4)$$

where J_e is the moment of inertia of the engine;

J_w is the moment of inertia of the wheel.

r_r – the rolling radius of the driving wheels of the tractor, m;

According to the value of the engine rotation frequency n_e, the forward speed of the tractor is determined depending on:

$$V_v=\frac{n_e\cdot\pi\cdot r_r}{U_{tr}\cdot 30}. \quad (5)$$

The processes of acceleration of a tractor with a locked clutch, deceleration with a disconnected and connected engine are described by differential equations that are solved by the Runge-Kutta method. By solving systems of differential equations that describe the mode of operation of a tractor with a trailer, the average values of the parameters that determine the mode of operation of the engine are determined at each section of the cycle.

The formula for the indicator torque of the diesel engine of the mathematical model of the movement of the wheeled tractor includes the value of the cyclic fuel supply (1) by the high-pressure pump. According to the literature, the cyclic supply depends on the viscosity of the fuel. This value was obtained from the characteristics of the fuel supply of the pump, obtained on an engineless bench when using biodiesel fuel and was described by a polynomial in the form of a dependence on the position of the fuel pump rail h_p and the frequency of rotation of the pump camshaft n_p:

$$q_c=\begin{pmatrix} b_0+b_1\cdot h_p+b_2\cdot n_p+b_{11}\cdot h_p^2+ \\ +b_{22}\cdot n_p^2+b_{12}\cdot h_p\cdot n_p \end{pmatrix}. \quad (6)$$

Before obtaining the characteristics, the biodiesel fuel was heated to a temperature of 60 °C, as a result of which its viscosity approached the viscosity of petroleum fuel, and the values of cyclic supply are close to the values of cyclic supply of petroleum fuel.

The mathematical model of the movement of the tractor over DC makes it possible to calculate the specific fuel consumption and the specific mass emissions of the tractor based on the concentrations of these substances in EG and the consumption of different types of fuel and air. Emissions of harmful substances from EG over the period of movement in the cycle:

$$G_{ic}=\sum\Delta G_i. \quad (7)$$

By solving the equations of the mathematical model at each section of the cycle, the parameters characterizing the engine's operating mode are determined. Engine performance is described by polynomial dependences. Emissions of harmful substances and fuel consumption are determined by average values of mode parameters and polynomial models.

To compare the toxicity of EG gases of the tractor engine, the total specific emissions of normalized harmful substances during the operation of the engine per cycle on petroleum fuel and biofuel were determined, reduced to CO carbon monoxide:

$$G_{CO}=A\cdot m_{CO}+B\cdot m_{C_mH_n}+C\cdot m_{NO_x}+D\cdot m_c, \quad (8)$$

where m_{CO}, $m_{C_mH_n}$, m_{NO_x}, m_c – specific emissions of carbon monoxide, hydrocarbons, nitrogen oxides, and soot per driving cycle, respectively, g/km;

A, B, C, D are aggressiveness coefficients of the corresponding components.

The values of aggressiveness coefficients in the current studies are taken as follows: A_{CO}=1, $B_{C_mH_n}=3.16$, $C_{NO_x}=41.1$, D_c=200 [13].

5. Results of investigating the influence of the type of fuel used on the environmental performance of a diesel engine in a wheeled tractor

5. 1. Results of studying biofuel indicators

The studied fuel (MEVO) was obtained by the well-known method of transesterification. To compare the thermal energy properties of biodiesel fuels, which differ among themselves in terms of elemental composition, the lower heat of combustion was calculated. To this end, the elemental composition of the new biofuel was determined according to the content of fatty acids in sunflower oil (Table 1) based on the procedure used by authors to calculate the composition of other biofuels [14]. For comparison, the table also includes data on rapeseed methyl ether (RME).

The calculations demonstrate that a smaller amount of carbon in the molecules of biodiesel fuels leads to a decrease in their lower heat of combustion. Therefore, to obtain the same effective power of a diesel engine when operating on mineral diesel fuel and biodiesel fuels, the specific effective fuel consumption is greater in the case of using biofuels.

Some deterioration of diesel performance when working on biofuels is caused by their higher viscosity compared to mineral fuel. The effect of increased fuel viscosity is mainly reduced to the deterioration of injection, its lag and delay, and to increased loads in the fuel pump drive. Therefore, it is suggested that this biofuel be used in a state heated to 65 °C. In this case, the viscosity of biofuel approaches the viscosity of mineral diesel fuel.

In order to ensure the regulatory technical and economic indicators of diesel engines, biofuel is needed, which has the same operational characteristics as mineral diesel fuel. Therefore, currently biofuels are usually used in mixtures with mineral diesel fuel.

Table 1 demonstrates that MEVO has twice the viscosity of mineral diesel fuel. The required viscosity value can be obtained by mixing MEVO with diesel fuel. Addition of 25 % MEVO allows obtaining an acceptable value of the viscosity of the mixed fuel.

Table 1

Physicochemical properties of the studied fuels

Indicator	Fuel		
	DF	MEPO	MEVO
Density at 20 °C, kg/m^3	830	880	886
Kinematic viscosity at 20 C, mm^2/s	3.8	5.6	7.0
The lower calorific value, MJ/kg	42.5	37.5	37.2
Cetane number	45	48	47
Solidification temperature, °C	–35	–12	–17
The amount of air required for complete combustion of 1 kg of fuel, kg	14.3	12.7	12.5
Content, % (wt.):	–	–	–
Carbon C	87.0	77.5	76.7
Hydrogen H	12.6	12.0	12.2
Oxygen O	0.4	10.5	11.1

5. 2. Results of investigating diesel engine indicators when working on biofuel

Bench tests of the D-243 diesel engine during its operation on MEVO, mineral DF, and mixtures of these fuels were carried out. As a result of the bench tests of the D-243 diesel engine when operating on different fuels, load characteristics (Fig. 1) were obtained at different rotation frequencies with the measurement of HS emissions. The figure shows the results of research on the mode of maximum torque, which is the most typical for tractor engines. As can be seen from the given characteristics, the diesel power N_e when working on these fuels is practically the same.

In the case of the operation of a diesel engine on MEVO, there is an increase in the specific consumption of fuel g_e within 12 % as a result of a lower heat of combustion.

There is an increase in the concentration of nitrogen oxides NO_x in the exhaust gases up to 10 % due to a higher oxygen content in the MEVO and an increase in the temperature of the working fluid in the cylinders of the diesel engine. The smoke of EG D is lower when working on MEVO under all loading and speed modes. At loads close to the maximum, the reduction of EG smoke is up to 40 %. This indicates more complete combustion of soot in the engine cylinders. The concentration of incomplete combustion products at low loads is higher when working on MEVO, but at high loads the content of CO carbon monoxide and CH hydrocarbons is lower by 3 % and 24 %. The results were obtained without changing the diesel engine settings.

The performance of the engine when operating on mixed fuels has intermediate values between the performance on petroleum fuel and biofuel. The EG temperature of the diesel engine when working on the compared fuels is practically the same in the entire range of loading modes.

The calculation of the coefficients of polynomial models during the operation of a diesel engine on different fuels and under different modes was performed by multivariate regression of experimental data using the method of least squares.

The adequacy of the polynomial models describing the D-243 diesel engine as a fuel consumer and a source of harmful emissions was tested using Fisher's *F*-test. The calculation established that the correlation coefficient is approximately equal to 1. The calculated values of the Fisher criterion (F_p) do not exceed the tabulated values. So, with a confidence level of 95 %, polynomial dependences can be considered adequate.

The performance of a diesel engine when operating on mineral fuel, biofuel, and its mixtures with mineral fuel under different modes are described by polynomials of the third order (1). For example, the content of nitrogen oxides in the exhaust gases from the engine is described by the dependence:

$$\begin{aligned}NO_x = &-5.05\cdot 10^{-7}\cdot n_e\cdot M_e^2-1.95\cdot 10^{-3}\cdot C_{bdf}\cdot M_e^2-\\ &-2.47\cdot 10^{-4}\cdot M_e^3+0.074\cdot M_e^3-2.32\cdot 10^{-5}\cdot n_e\times\\ &\times C_{bdf}\cdot M_e+1.865\cdot C_{bdf}^2\cdot M_e-0.796\cdot C_{bdf}\cdot M_e+\\ &+3.777\cdot M_e-1.87\cdot 10^{-3}\cdot n_e\cdot M_e+3.00\cdot 10^{-7}\times\\ &\times n_e^2\cdot M_e-3.84\cdot 10^{-4}\cdot n_e\cdot C_{bdf}^2-840.403\cdot C_{bdf}^3+\\ &+1.22\cdot 10^3\cdot C_{bdf}^2-413.523\cdot C_{bdf}-2.88\cdot 10^{-3}\cdot n_e\cdot\times\\ &\times C_{bdf}+2.31\cdot 10^{-6}\cdot n_e^2\cdot C_{bdf}+298.01-0.461\cdot n_e+\\ &+2.84\cdot 10^{-4}\cdot n_e^2-6.04\cdot 10^{-8}\cdot n_e^3.\end{aligned} \quad (9)$$

Dependences for the investigated output variables in the range of engine revolutions 1200–2000 in the form of response surfaces are shown in Fig. 2.

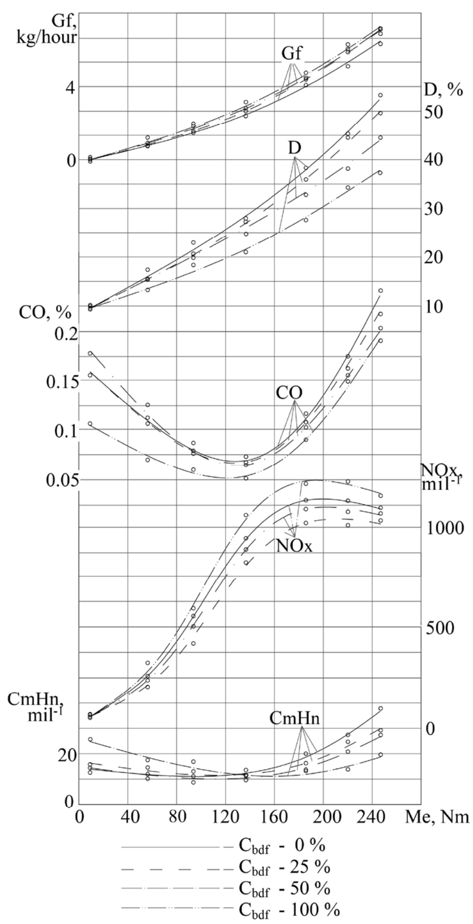

Fig. 1. Load characteristic with measurement of exhaust gas toxicity of diesel engine D-243 (n_e=1400 min^{-1}) during its operation on different types of fuels

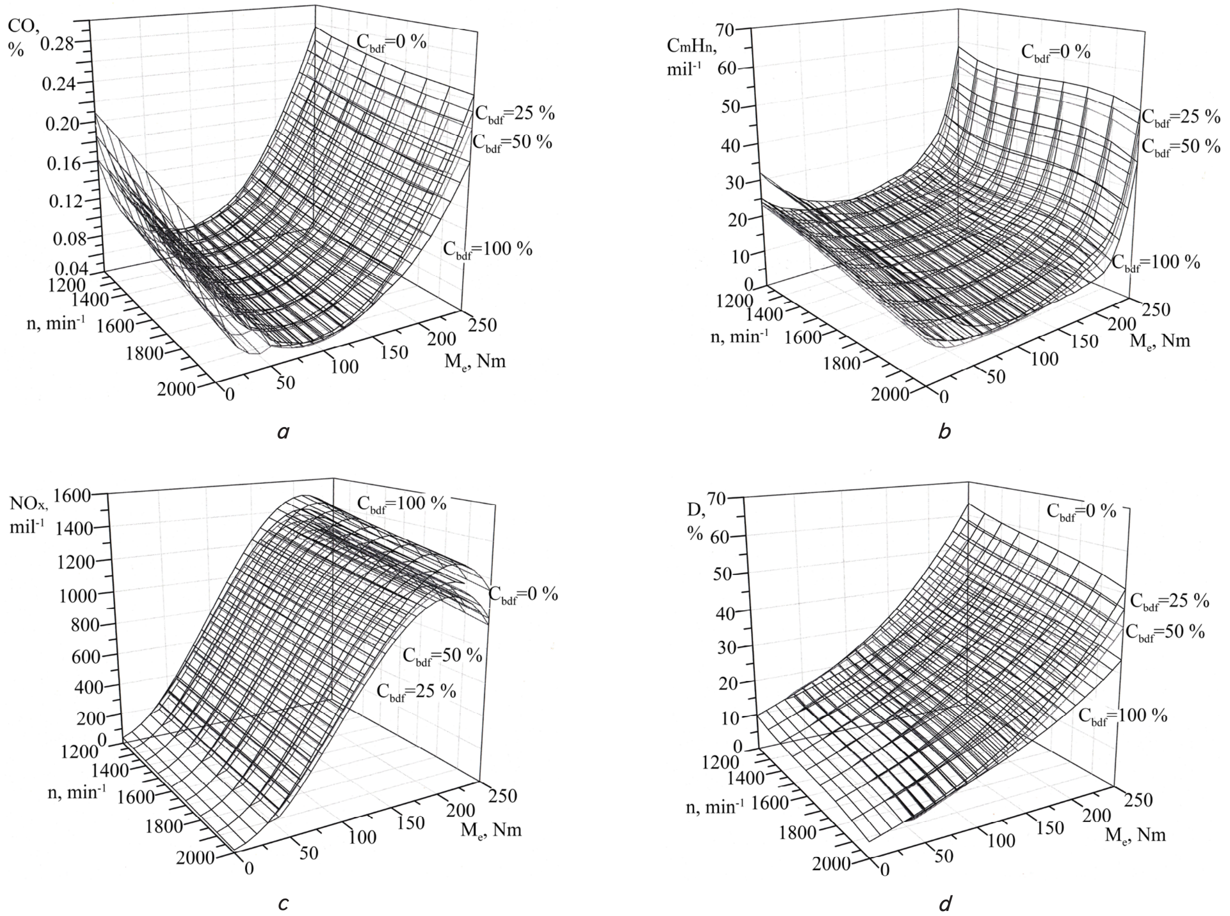

Fig. 2. Estimated environmental characteristics of the D-243 diesel engine when operating on biofuel and its mixtures with mineral diesel fuel: *a* – CO; *b* – C_mH_n; *c* – NO_x; *d* – D

5. 3. Evaluating the total toxicity of the exhaust gases from a diesel engine in a wheeled tractor during its operation on biofuel

To carry out theoretical research, a driving cycle of a tractor with a trailer was formed, the diagram of which is shown in Fig. 3. The cycle includes the basic modes of movement: acceleration, movement at a constant speed, and deceleration.

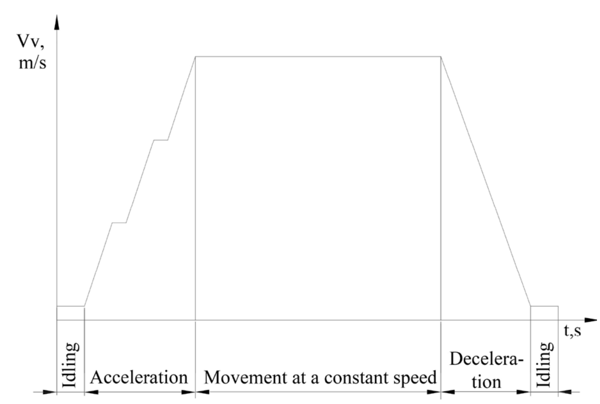

Fig. 3. Scheme of the accepted driving cycle of a tractor with a trailer

With the help of a refined mathematical model – dependences (1) to (8) – the specific mass emissions of individual fuel tanks (g_{CO}, g_{CmHn}, g_{NOx}, g_C), total road emissions of fuel tanks, as well as fuel consumption g_f of the MTZ-80 tractor during its movement with trailer were calculated per cycle. The calculation was carried out for two types of fuel: mineral DF and biofuel MEVO. At the same time, the mass of the trailer towed by the tractor and the traffic conditions, which are characterized by the coefficient of rolling resistance of the wheels and the angle of inclination of the longitudinal profile of the road, were taken into account. Based on these data, graphical dependences were constructed (Fig. 4).

The calculation of the tractor's parameters on the mathematical model showed results similar to those obtained by the experiment on the engine. When using biofuel, emissions with exhaust gases of soot and products of incomplete combustion of fuel (carbon monoxide, CO, and hydrocarbons) are significantly reduced under medium and high load modes.

The total specific emissions, reduced to carbon monoxide CO, are 1.1 times higher than a diesel engine running on mineral fuel. Emissions of almost all HS increase with the increase in the weight of the cargo transported by the tractor with a trailer.

Adequacy of the model of the movement of a tractor with a trailer per cycle during the operation of a diesel engine on biofuel – dependences (1) to (6) – was checked by comparing the calculated indicators characterizing the engine operation mode and traction-speed indicators of the tractor with experimentally obtained data (Fig. 4) when the MTZ-80 tractor with a trailer is moving. Before the tests, the biodiesel fuel was heated.

The weight of the transported cargo was 3700 kg, the movement was carried out on a horizontal section of the asphalt road, the movement was carried out from the 6th gear of the transport row.

Fig. 5 shows the oscillograms of changes in the parameters of the tractor while driving with a trailer according to the accepted cycle (tractor acceleration mode). On these oscillograms: ϕ_p – position of the fuel supply control lever, h_p – position of the fuel pump rail, V_v – speed of the tractor.

During the comparison, the following conditions were observed:

– gear shifting time and final engine speed in each gear in the experiment and in the calculation are the same;

– the law of movement of the fuel supply control lever is taken into account in the same way as in the experiment;

– the clutch engagement time when the tractor is moving is taken to be equal to 1 s.

Before the tests, sensors were installed on the fuel pump: a fuel control lever position sensor and a fuel pump rail position sensor. A speed sensor was installed on the driving wheel of the tractor. Then the frequency of rotation of the wheel was converted into the speed of the tractor. Sensor readings were recorded on a K12–22 magnetoelectric oscilloscope.

A fuel pump was installed on the engine, with which non-engine and engine tests of the engine were carried out. Runs were conducted on a road with an asphalt-concrete surface and a horizontal profile with f=0.016 and a load weighing 3000 kg in a trailer. Acceleration was carried out in the 6th, 7th, and 9th gears of the transport row by moving the fuel control lever to 100 % in each gear, the time for switching gears was within 2 seconds.

As can be seen from the plots in Fig. 5, the nature of change in the parameters of the tractor with a trailer when moving over the cycle, obtained by calculation and experimentally, is practically the same. There is a slight difference in time between the calculated and experimental data (within 0.5 s).

Thus, the comparison demonstrates that the mathematical model in general correctly describes the qualitative and quantitative changes in the tractor's indicators during movement. This makes it possible to use it to calculate the parameters characterizing the operating mode, fuel economy, and environmental indicators of the MTZ-80 tractor with a trailer during transport operations.

Biodiesel fuel is usually used in a mixture with mineral DF. Fig. 6 shows the effect of MEVO content in a mixture with mineral fuel on the performance of the MTZ-80 tractor when it is moving with a trailer. It can be seen from the plots (Fig. 6) that with an increase in the content of biofuel C_{bdf}, the fuel consumption in energy units decreases and the emissions of dispersed particles C decrease. The minimum emissions of hydrocarbons and carbon monoxide occur at a biofuel content of 50 %, and the minimum emissions of nitrogen oxides and the minimum total emissions reduced to carbon monoxide, with a biofuel content of 25 %.

Comparative calculation-theoretical studies of ecological and fuel-economic indicators of transport vehicles over the same driving cycle allow the most objective assessment of the total toxicity of exhaust gases when working on different fuels. The total toxicity of exhaust gases over the driving cycle of a wheeled tractor when working on biofuel is 371.7. The same indicator when working on diesel fuel is 412.2.

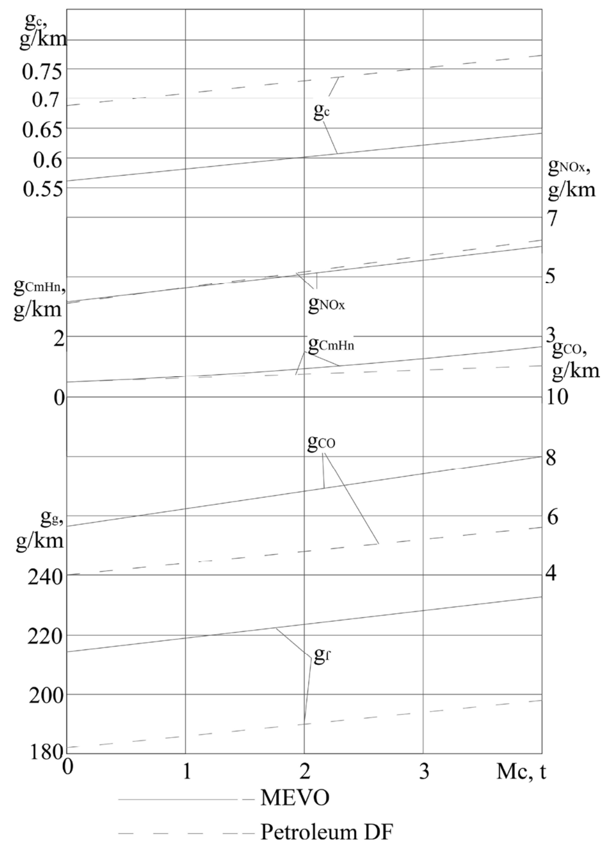

Fig. 4. Dependence of fuel consumption and emissions of harmful substances on the cargo weight M_c of the MTZ-80 tractor during engine operation on different types of fuel

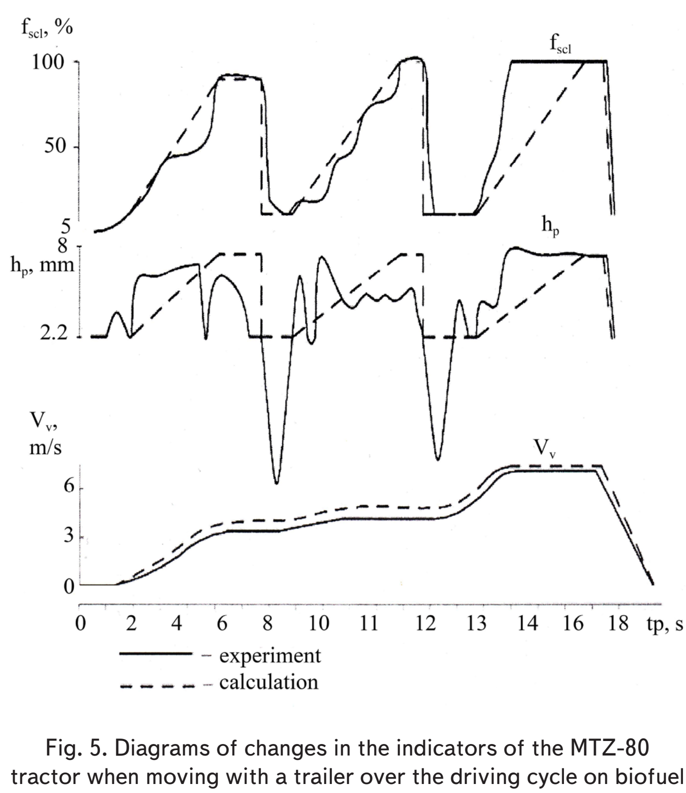

Fig. 5. Diagrams of changes in the indicators of the MTZ-80 tractor when moving with a trailer over the driving cycle on biofuel (t – tractor acceleration time)

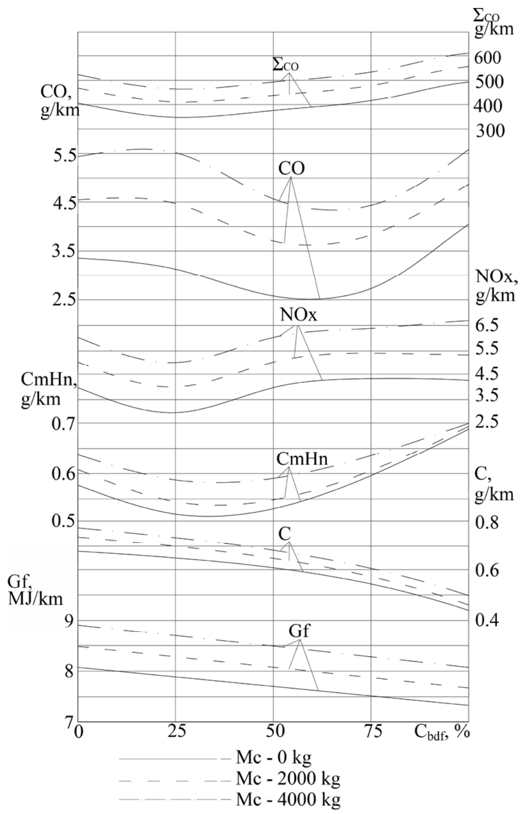

Fig. 6. Influence of the biofuel content C_{bdf} in a mixture with mineral fuel on the performance of the MTZ-80 tractor at different weights of transported cargo M_c

6. Discussion of results of investigating the impact of biofuel on the environmental indicators of diesel engine

Our result of reducing emissions of incomplete combustion products: carbon monoxide, CO, and hydrocarbons, as well as soot, can be explained by the higher content of oxygen in the elementary composition of biofuel (Table 1). Some increase in emissions of nitrogen oxides NO_x can be explained by the same increased content of oxygen in the composition of biofuel and sufficiently high temperature of the working fluid in the combustion chambers.

The decrease in the content of soot C in the exhaust gases of a diesel engine as the content of biofuel increases (Fig. 6) can be explained by the better combustion of soot due to the increase in the content of oxygen in the fuel. After all, biodiesel is an oxygen-containing fuel (Table 1). Minimum emissions of nitrogen oxides NO_x and hydrocarbons CH with a biofuel content of 25–30 % – by improving combustion conditions at this concentration of biofuel. Thus, it is possible to explain the minimum emissions of CO carbon monoxide with a biofuel content of 60 %. With a further increase in the content of biofuel, the temperature of the working fluid in the combustion chambers increases and the conditions for an increase in the amount of NO_x appear.

In contrast to [3–12], in which the results of changes in emissions of harmful substances with exhaust gases of diesel engines when operating on biofuels were obtained, in this work the values of the total toxicity of exhaust gases of a wheeled tractor when working on different fuels were obtained. This became possible owing to the application of the method of determining the total toxicity of exhaust gases of a wheeled tractor over the driving cycle. This will make it possible to objectively compare the overall environmental friendliness of technological vehicles when using different types of fuels.

The limitation of the application of our results at present may be the insufficiency of the resource base of raw materials for obtaining MEVO. The component of this biofuel is methanol. It is a toxic and aggressive substance for engine materials. Its presence in the fuel could lead to a decrease in engine life.

The current research may be advanced towards using raw materials, the reserves of which are significant. Such raw materials could involve disposed animal fats. Also, instead of methanol, it is advisable to use less toxic and less aggressive components (ethanol, isopropanol, etc.). Difficulties on this path are the need to attract specialists from other industries to design such fuels.

The practical value is expansion of the fuel base of enterprises through the use of biofuel obtained from waste.

7. Conclusions

1. The physical-chemical properties of methyl ether from spent sunflower oil were determined: density, kinematic viscosity, solidification temperature. These indicators are close to the standard (rapeseed oil methyl ether). In MEVO, the density is higher by 6 kg/m^3, the kinematic viscosity is higher by 1.4 mm^2/s, and the solidification temperature is lower by 5 °C.

2. Experimental studies have confirmed the possibility of exploiting methyl ether from used oil in auto-tractor diesel engines. The operation of a diesel engine on biodiesel fuel is accompanied by a reduction in the smoke level of exhaust gases by up to 40 % compared to diesel fuel and a reduction in carbon monoxide and hydrocarbon emissions at medium to heavy loads.

3. Based on the results of bench research, polynomial dependences were constructed that describe diesel engine as a source of harmful emissions. Mathematical modeling established that the total specific emissions of harmful substances reduced to CO carbon monoxide are 1.1 times lower in a tractor running on biofuel than when using mineral fuel. The total toxicity of exhaust gases when working on biofuel is 371.7. The same indicator when working on diesel fuel is 412.2.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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