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Alternative fuels in internal combustion engines

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Abstract: Automobile industry is one of the most developed industries in Ukraine and in the world today. The ever-increasing demand for transportation leads to an increase in demand for fuel, which in turn increases its deficit and value. Therefore, the high cost of traditional hydrocarbon fuels and the constant reduction of their world reserves compels scientists to find renewable biofuels. The authors are investigating the possibility of using alternative fuels derived from the alcohol industry waste, in pure form and as additives to hydrocarbon fuels. According to the results of the study the main technical and operational properties of alternative fuels received on the basis of A-92 petrol and fusel oils, experimental values of density, viscosity, distillation temperature on the ENGLER machine, temperature of formation steam congestion, their optimal percentages in the mix for different types were obtained internal combustion engines. Addition of fusel oils to A-92 gasoline leads to improvement of the viscosity-temperature characteristics of formed mixtures, increase in the temperature of formation steam cork and ultimately reduces the need for 10-12% of the consumption of fuels and to solve the problem of recycling fusel oils.

Keywords: gasoline, addition, fusel oil, improvement, density, temperature, viscosity, economy, recycling

1. Introduction

Automobile industry is one of the most developed industries in Ukraine and in the world today. The ever-increasing demand for transportation leads to an increase in demand for fuel, which in turn increases its deficit.

Characteristics of most fuels currently in use no longer satisfy the ever-increasing requirements of their fire safety and the content of harmful impurities in the exhaust gases. The growth of the environmental requirements of Euro-5,6 for fuels leads to an increase in oil refining costs, and, ultimately, to an increase in fuel prices.

Consequently, the high cost of traditional hydrocarbon fuels and the constant reduction of their world reserves compels scientists to find renewable biofuels.

In Brazil and elsewhere in the world, alcohols are used as an alternative fuel in their pure form, and in mixtures with gasoline in certain ratios today.

2. Literature review

Ethanol or E85 (15 % gasoline) is commercially used on the fuel market, for example, Brazil and Sweden. It is also used as fuel in a mixture of up to 10 % of gasoline in the EU and the US [1].

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In [2] it is proposed to apply higher alcohols as an anti-knock gasoline additive, which will increase its environmental safety. Since lead and other heavy metals used earlier are very harmful to the environment [3].

In Brazil and other countries at present are widely used as an alternative fuel alcohols both in pure form and in mixtures with gasoline in particular proportions.

In [4], it is proposed usage higher alcohols as an anti-knock gasoline additive because the lead used earlier is very harmful to humans and the environment [5].

Usage of methanol as an additive to gasoline is made in China, a mixture containing methanol from M5 to M30 used in standard gasoline engines, and from M85 to the M100 methanol used in special machines [6].

Although usage of methanol is very dangerous for humans because of its high toxicity, it reduces the risk of fire by 95 % and the negative impact on the environment from leakage and is derived from biological regenerative raw materials, and therefore methanol is a promising substitute gasoline [7].

The authors [8] investigated the economic impact of using bioethanol as motor fuel. According to research results, for used bioethanol and gasoline prices, it has been established that with an increase in the percentage of bioethanol content in equivalent fuel to 80 % there is an increase in the economic efficiency of using bioethanol due to the use of low-octane gasoline in fuel. Reduction in the cost of equivalent fuels ranges from 5.8 % to 30 %.

Results of the research in [9] show that usage methanol in the power supply system of automobiles, it is possible to improve the environmental performance compared to gasoline, reducing CO_2 and NO_x emissions by 20 % and 90 %, respectively.

Usage of methanol and ethanol in engines with spark ignition was investigated in [10]. Methanol and ethanol are compatible with existing fuels and are easily stored in a vehicle. This study shows that thermal fuel efficiency is somewhat improved on gasoline. NO_x emissions are significantly reduced for fuels with higher water content. The study of methanol as a fuel was also carried out in [11]. The physical and chemical properties of ethanol and gasoline related to the DIC are considered.

Methanol in comparison with gasoline has a high heat of evaporation, which is a significant advantage over gasoline.

Similar results were obtained in [12], as a result of the research, good environmental performance of the engine and the EGR valve was ensured, as well as not a significant increase in fuel consumption, although, as noted, for example, in the work.

Of the other processes [13] are also influenced by fuel consumption namely the work of the automobile's friction couples.

In this work, the authors [14] investigated usage mixture of gasoline and methanol. Measured spent gases of the car on the content of hydrocarbons, methanol and aldehydes, as well as the trend of carbon emissions. According to the results, the emissions of aldehyde on methanol were approximately one order higher than those resulting from usage of commercial fuels and the hydrocarbon composition of the spent gases was similar to commercial fuels.

Therefore, the production of fuel alcohol can significantly reduce the demand for commercial fuels, and the use of it in the form of mixtures with gasoline does not require changes in the design of the power supply [15].

An important competitor of hydrocarbon fuels for engines and alcohols is hydrogen in which combustion products do not contain toxic products of incomplete combustion of hydrocarbon fuels and alcohols (CO, C_nH_m, NO) [16].

Usage of hydrogen based fuels was investigated in [17].

The advantages of hydrogen as fuel are improving fuel economy and environmental performance, the ability to adapt fuel for all types of engines and power plants.

However, for usage of hydrogen as a fuel for road transport, it is necessary to solve the problem of its mass and cheap production, as well as to create reliable means of storage of hydrogen fuel on board the car [18].

Fighting against harmful emissions of engines is mainly solved by the neutralization of spent gases in the vehicle's exhaust system by oxidizing waste gases by supplying them with additional air in the thermal, absorption of toxic components by liquid in liquid neutralizers, the use of catalytic converters and soot filters in diesel engines, the transfer of diesel engines to alternative fuels [19].

The high level of purification of spent gases and the use of alternative fuels in road transport will greatly increase the environmental safety of the car for the environment.

Therefore, the main purpose of the work is to explore the possibility of using the waste alcohol industry as an alternative fuel.

To achieve this goal were formulated following tasks:

- investigation of technical and operational indicators of gasoline, depending on the percentage of volumetric content of fusel oils;
- the experimental installation of optimum content of fusel oils in the alternative fuel produced;
- investigation of environmental and technical and economic parameters of the internal combustion engine in the process of using alternative fuels.

3. Materials and Methods

Main technical and operational indicators of blends of commercial fuels with fusel oils are density, kinematic viscosity, temperature of distillation, etc. were investigated experimentally.

During the course of experimental research and processing of the results, methods of least squares and mathematical statistics were used.

Methods of research were developed taking into account the basic physical and chemical properties of fusel oils. All experiments in this work were carried out on fusel oils obtained from the Ivano-Frankivsk regional state association of alcoholic and alcoholic beverages "Knyaginin" that meet the standard [20] and were checked in the chemical laboratory of the said enterprise.

Process of mixing fusel oils with commercial gasoline A-92 was carried out in a closed vessel using an electric stirrer for 5 minutes. During this time there was a complete dissolution of fusel oils in gasoline A-92.

The main studies of the environmental performance of the engine were performed on the developed installation for study of operational and environmental performance of the engine on alternative fuel Fig. 1. Load for the engine (8) is generated by the electric generator (4) and maintained by the regulation of current on the rotor of the electric motor using a rheostat (2).

To study the effects of additives of fusel oils on commercial gasoline A-92 on the toxicity of spent gases in the scheme of the experimental installation used an engine that is not equipped with a catalytic converter.

Toxicity of the spent gases was investigated using the automotive gas analyzer AvtoTest 02.03P.

Research of technical and operational indicators is carried out for fuel mixtures, created by mixing fusel oils with gasoline in proportions recommended in [21].

Mixing was carried out at a temperature of components of 20 ^{o}C and atmospheric pressure of 740 mm. ht Art.

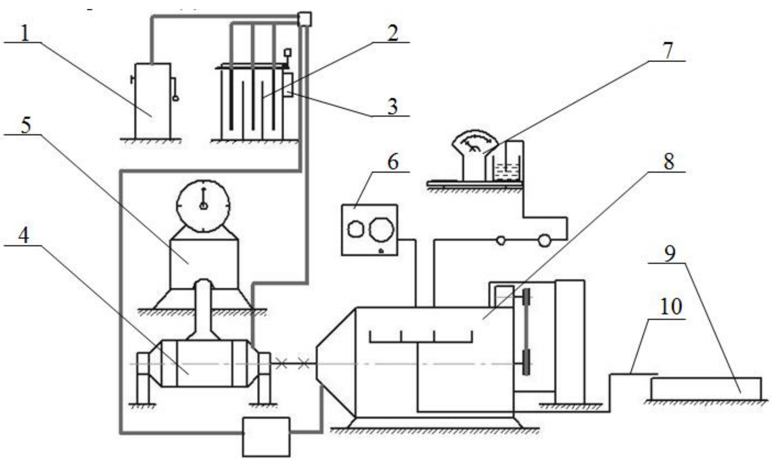

Figure 1. Installation for the study of operational and environmental performance of the engine on alternative fuels: *1* - power cabinet; *2* - rheostat; *3* - regulator of depth of immersion of electrodes; *4* - electric generator; 5 - weight to determine the load of the model VKM-32; *6* - panel of control-measuring devices; *7* - weight to determine mass fuel consumption; *8* - carburetor engine ZIL-130; *9* - exhaust trac; *10* - pipeline.

Viscosity and density of gasoline A-92 significantly affect the supply of fuel through the nozzle. The higher viscosity of the fuel, the less its rate of flow through the injector nozzle and density increasing with increase of mass flow. The density of gasoline also affect the composition of the fuel mixture and quality of training in the combustion chamber of internal combustion engine, as well as high density leads to poor mixing of fuel produced drops large diameter that does not do it completely burned in the camera (mechanical incomplete combustion), as a result - increase in specific fuel consumption.

The results of experiments to determine the density and viscosity of the mixture of gasoline and FO shown in Fig. 2.

Shown in Fig. 2 curve of density and viscosity are described in the following approximation dependences of correlation coefficients of 0,954 and 0,963 respectively:

$$\rho_f = a + b \cdot V_{FO}, \tag{1}$$

$$\upsilon_f = a_1 + b_1 V_{FO}, \tag{2}$$

where a, b, a_1, b_1, - experimental coefficients listed in the table 1 and determined by the least squares method.

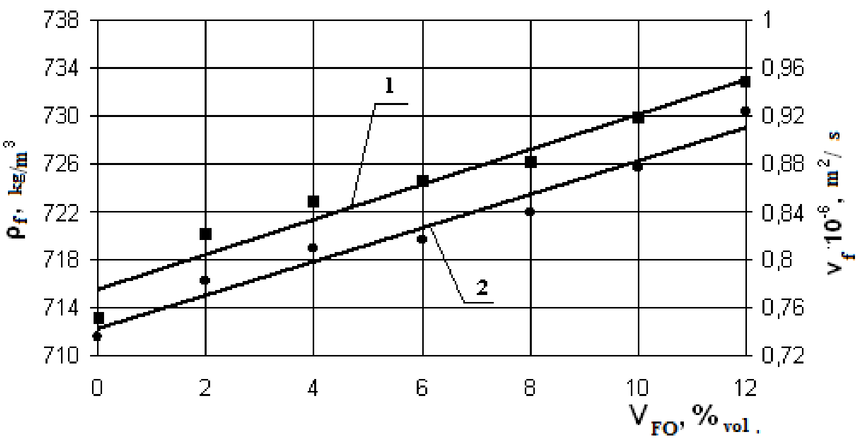

Figure 2. Effect of volume content of fusel oils V_{FO} on kinematic viscosity ν_f and density ρ_f fuel mixtures: *1* - density fuel; *2* - kinematic viscosity fuel.

Table 1. Experimental coefficients in equations (1) and (2)

Values of the coefficients			
ρ_F, **kg/m³**		ν_F, **m²/s**	
a	***b***	***a₁***	***b₁***
715.55	1.14554	$0.7426 \cdot 10^{-6}$	$1.4 \cdot 10^{-8}$

Small value of the coefficients at V_{FO} in equation (2) show that the kinematic viscosity derived fuel mixtures are not significantly different from the viscosity of pure gasoline. So fusel oil additive to gasoline of up to 12 % vol. not adversely affect the flow of the mixture through the filter system power.

Fig. 3 shows a graphical dependence of the temperature in the engine compartment, where the formation of vapor lock in the system power output from the percentage in gasoline fusel oils.

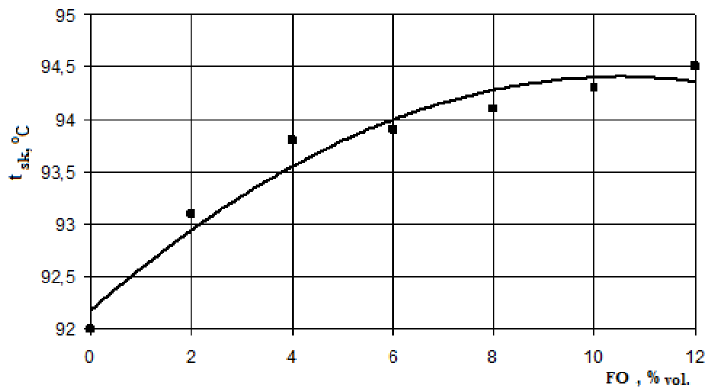

Figure 3. Change of temperature formation of vapor lock t_{sk} in the system power engine depending on the percentage of gasoline fusel oil.

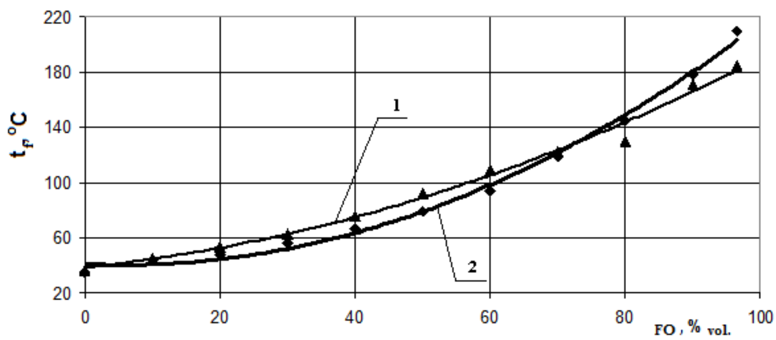

Figure 4. Effect of fusel oil content (% vol.) at temperature t_f distillation of petrol: *1* - A-92; *2* - mixture of petrol A-92 and 12 % vol. FO.

Important indicator for gasoline according to DSTU is a fractional composition that affects the engine performance in all operating modes, depending on which factors such as the ease of starting engine, speed of warming up, usage the wear of the cylinder-piston group, lacquer and formation of the nail on the engine parts, composition and volume of combustion products.

Fractional composition of the mixtures was investigated on a standard device (the device of the ENGLER) according to GOST.

Results of researches the temperature of distillation ogasoline and mixtures of gasoline with fusel oils 2, 4, 6, 8, 10, 12 % by volume filed under table 2.

Table 2. Fractional composition of the mixtures

Volume of waste gasoline, %	**Boiling point of the mixture of gasoline and FO, °C**						
	Gasoline A-92	**1 % vol. FO**	**2 % vol. FO**	**4 % vol. FO**	**5 % vol. FO**	**10 % vol. FO**	**15 % vol. FO**
Start distillation	35	35	35	36	36	36	37
10	44	45	44	43	43	43	45
50	79	80	81	81	81.5	84	92
90	178	178	175	178	179	178	171
End of distillation	210	209	209	208	208	204	185

The temperature of the beginning of boiling (t.b.) of gasoline affects not only the pressure of saturated vapors, but also on its physical stability. To ensure normal fuel storage conditions, this temperature according to the State Standard should be 30°C or more. An additive to fusel oil gasoline slightly increases this temperature (see Table 2), which improves fuel storage conditions.

Temperature of 10% ebullition ($t_{10\%}$) characterizes the ease of starting an ICE and the intensity of wear during start-up. It should be in accordance with DSTU for gasoline not more than 75 °C, as evident from the experiments, the temperature of mixture corresponds to these limits.

Temperature of 50% boiling ($t_{50\%}$) affects the ICE heating, its dynamism, the intensity of acceleration of the car to a certain speed after the sharp opening of the throttle valve. It should not exceed 120 ºC for gasoline. This condition will also be ensured as the temperature of the $t_{50\%}$ boiling mixture corresponds to these limits.

Important operational indicator for fuels is their propensity to burn the carbon in the combustion chamber. It is known that the construction of the engine and fuel composition have a significant influence on the formation of carbon in the combustion chamber. It is established that the formation of carbon significantly affects the high content of high-boiling olefinic and aromatic hydrocarbons in fuel, and therefore their content in fuel is limited to 25 and 55% vol.

Since fusel oils contain higher alcohols, when using them as additives to commercial fuels, a slight increase in the ability to form a carbon in the combustion chamber may be insignificant.

In Fig. 5 the experimental dependence of changing in the volume of the residual in the flask, together with the losses of fuel and fuel mixtures in distillation, is constructed, depending on the percentage volumetric content of fusel oils in it.

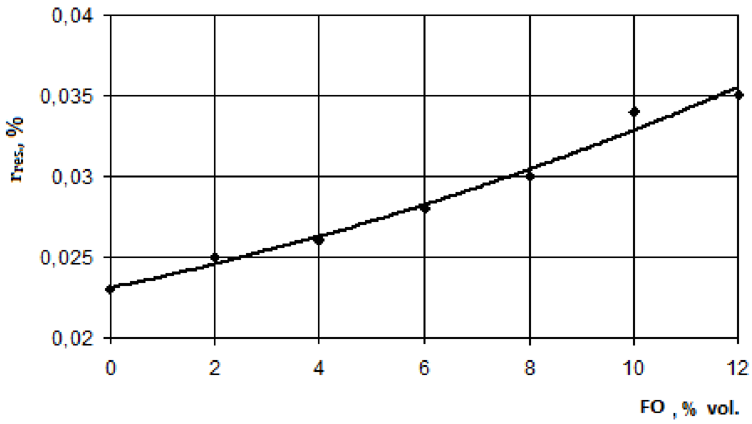

Figure 5. Dependence of the relative volume of the residual $r_{res.}$, % of the content of fusel oils in gasoline A-92.

Relative amount of residue in the flask r_i calculated from the relationship:

$$r_i = \frac{V_{rem.}}{V_{gen.}}, \quad (3)$$

where V_{gen} - the total amount of fuel taken for distillation, ml.;

$V_{rem.}$- amount of fuel remaining in the flask after distillation, ml.

As shown in Fig. 5 dependence adding fusel oils in fuel leads to a slight increase in the residue flask and loss of fuel during distillation, but they do not exceed 4 % of that regulated standards for gasoline and, therefore, the addition of fusel oils to gasoline up to 12 % by volume is acceptable. On the content of CO, NO i C_nH_m in the spent gases of gasoline ICE impact angle of inflammation, and therefore, in order to exclude the impact of this angle during the experiment, it did not change.

Experiment results are given in Tables 3-6.

Experimental dependence of the content of CO, C_nH_m, NO in the spent gases of the experimental engine on the volumetric content of fusel oil in fuel mixtures VCM, while working in idle mode, is shown in Fig. 6 and 7.

From Fig. 6 and 7 it follows that as a result of an increase in the content of fusel oil in fuel up to 10 %, an increase in fuel consumption is observed due to an increase in the density of fuel mixtures (Fig. 2) and a slight increase in the concentration of hydrocarbons and nitrogen oxides in the spent gases of the engine.

Table 3. Results of determining the content of CO in the spent gases of the engine

The content of fusel oils, % vol.	Contents CO, % vol.			
	1	2	3	Average value
0	1.51	1.52	1.5	1.51
5	1.45	1.45	1.43	1.44
8	1.42	1.41	1.4	1.41
10	1.37	1.35	1.35	1.36

Table 4. Results of determining the content of C_nH_m in the spent gases of the engine

The content of fusel oils, % vol.	Contents C_nH_m, million $^{-1}$			
	1	2	3	Average value
0	1400	1400	1450	1416
5	1450	1450	1450	1450
8	1450	1500	1500	1483
10	1500	1500	1550	1550

Table 5. Results of determining the content NO in the spent gases of the engine

The content of fusel oils, % vol.	Contents NO, million $^{-1}$			
	1	2	3	Average value
0	210	200	210	210
5	240	240	230	236
8	260	250	260	257
10	270	280	280	276

Table 6. Results of determination of mass fuel consumption of the engine

The content of fusel oils, % vol.	Mass fuel consumption G, g/min			
	1	2	3	Average value
0	80	81	81	80.7
5	82	83	82	82.3
8	85	84	84	84.3
10	86	86	87	86.3

However, it should be noted that with increasing content of fusel oils in fuel, there is a decrease in the concentration of carbon monoxide (Fig. 6).

Experimental dependencies (Fig. 6) are approximated by the following equations:

$$CO = a_2 - b_2 \cdot V_{FO} - b_3 \cdot V^2_{FO} , \quad (4)$$

$$G = a_3 + b_4 \cdot V_{FO} + b_5 V^2_{FO} \quad (5)$$

where CO - concentration of carbon monoxide in the spent gases of the engine during its operation on fuel mixtures of gasoline with fusel oils, % vol.;

G - consumption of a fuel mixture of gasoline with fusel oils, g /min.

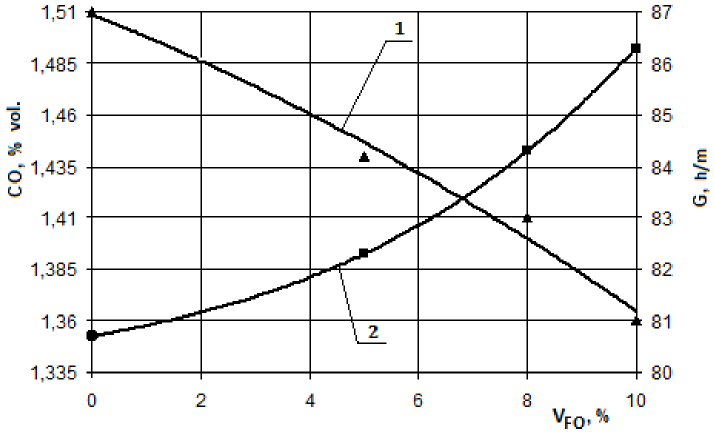

Figure 6. Dependence of the content of CO in the waste gases of the experimental engine and fuel consumption G from volumetric V_{FO} content to fuels of fusel oils: the correlation coefficients for the curves $\rho_1 = 0.98$ and $\rho_2 = 0.99$; *1* - the content of CO in the spent gases of the engine; *2* - minute fuel consumption G; idle mode.

In Table 7 shows the experimental coefficients for equations (4) and (5).

Table 7. Experimental coefficients for equations (4) and (5)

Value of coefficients					
CO, % vol.			G, g /min		
a_2	b_2	b_3	a_3	b_4	b_5
1.51	0.0105	0.0004	80.708	0.0635	0.0492

$$O = a_4 - b_6 \cdot V_{FO} + b_7 \cdot V^2_{FO} \quad (6)$$

$$C_nH_m = a_5 + b_8 \cdot V_{FO} + b_9 \cdot V^2_{FO} \quad (7)$$

where C_nH_m - the concentration of hydrocarbons in the waste gases of the engine ZIL-130 during its work on fuel mixtures of gasoline with fusel oils, million^{-1};

NO - concentration of nitrogen oxides in the spent gases of the ZIL-130 engine during its operation on fuel mixtures of gasoline with fusel oils, million^{-1}.

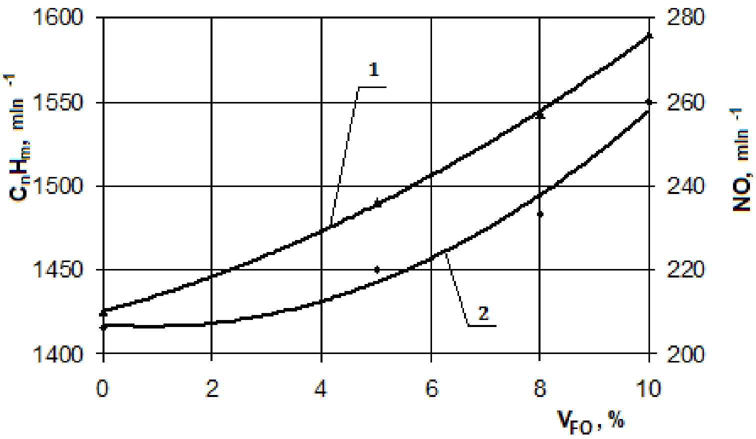

Figure 7. Dependence C_nH_m and NO content in the spent gases from the engine research V_{FO} volume content in the fuel fusel oil: the correlation coefficients for the curves $\rho_1 = 0.97$ and $\rho_2 = 0.99$; *1* - NO content in the spent gases of the engine; *2* - C_nH_m content in the spent gases of the engine; idle mode.

The experimental coefficients for equations (6) and (7) are given in Table 8

Table 8. Experimental coefficients for Eq. (6) and (7)

Value of coefficients					
NO, mln-1			**CnHm, mln-1**		
a4	**b6**	**b7**	**a5**	**b8**	**b9**
1417.4	2.614	1.5322	210.1	3.6053	0.2947

4. Results and discussion

Adding FO other brands of gasoline available only in small quantities because gasoline A-95 and A-98 have high octane, so the negative impact on their physical and technical indicators will not.

According to research conducted by the authors additive to gasoline A-92 in an amount up to 10 % fusel oil improves a number of performance indicators:

- increases octane fuel mixture, which will allow for the use of fuel mixtures of low octane gasoline;
- reduced vapor pressure, which reduces the likelihood of vapor lock in the system of power and loss ICE gasoline in storage, transportation and refueling vehicles;
- increasing the density of the fuel mixture from 710 to 727 kg/m^3, which reduces fuel loss through compaction, improves mixing in the cylinders of internal combustion engines.

Density value different grades of motor gasoline according to the standards ranges from 710 to 785 kg/m^3. Determined in experiments density fuel mixtures in the range from 713 to 734 and does not exceed the specified range, and a slight increase in the density of fuel mixture will affect the level of fuel in the float chamber compared to gasoline.

As can be seen from Fig. 6 and 7 addition to commercial gasoline A-92 fusel oils in the amount from 2 to 10% vol. leads to a decrease of the CO content in the spent gases of the ICE by 9.3%, an increase in fuel consumption by 6.5%, a 10.2% reduction in hydrocarbons and 16.9% increase in nitrogen oxides.

The growth of C_nH_m and NO in the spent gases of the engine will not create practical problems in the use of developed alternative fuels due to the presence of these compounds in the modern vehicle by efficient converters.

5. Conclusions

The experiments carried out are continuation of research on the possibility of using fusel oil - waste from the alcohol industry, as a component of commodity fuels and allowing to expand the base of alternative fuels.

As a result of research the technical and operational properties of the created alternative fuels, the correlation between the density values, the kinematic viscosity and the balance in the flask from the percentage content in the fuel of fusel oils was established.

Obtained results are described by approximation equations with rather high coefficients of correlation of 0.954 and 0.963, which confirms the adequacy of the obtained results.

Obtained and investigated alternative motor fuel is suitable for use in accelerated ICE with external mixture formation, which require the use of gasoline only with an ON≥95.

Usage fusel oils in conjunction with gasoline improves the environmental performance in terms of the content of CO in the waste gas of the internal combustion engine.

According to the results of the study, the addition of fusel oils to A-92 gasoline leads to improvement of the viscosity and temperature characteristics of formed mixtures, namely, viscosity, density, distillation temperature on the device of Engler and the temperature of formation of steam cork, and therefore as a result of their addition to gasoline allows to reduce by 10-12% the need for the latter and at the same time solve the problem of ecologically safe utilization of fossil oils without additional costs of energy resources, and the use of these additives does not require changes in power system design engines, making fusel oils promising alternative fuel.

Regarding environmental performance, the detected growth of C_nH_m and NO in the spent gases of the engine will not create practical problems of usage developed alternative fuels due to the presence of effective compounds of these compounds on the car.

Consequently, the addition to fossil oils A-92 gasoline makes it possible to improve their basic performance and solve the problem of waste recycling of the alcohol industry.

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