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ANALYSIS OF THE PERFORMANCE OF INTERNAL COMBUSTION ENGINES ON BIOETHANOL BLENDS IN MOUNTAIN ENVIRONMENTS

Introduction

Rapid advances in science and technology require the invention of high-quality fuel that could ensure proper functioning of new mechanisms. Surprisingly enough, the use of biofuels in cars has been proposed since the beginning of automotive history [1]. At first biofuels that were widely applied by well-known inventors and industrialists seemed to be highly promising; however, low oil prices have driven it out from the market. Steady growth of the rolling stock of motor transport, especially automobile transport, has resulted in the increase of fuel consumption [2, 3]. Since oil reserves are exhaustible, transportation sector has generated an interest in replacing petroleum-based fuels with renewable or alternative fuels, biofuel being one of them. In fact, researchers have developed various methods of reducing fuel consumption and atmosphere contamination with emissions from automobile engines. The world automotive industry faces the problem of developing and producing new economical and environmentally friendly fuels [4, 5].

Background

The world leaders for biofuel technologies are Brazil, the United States of America and the European Union. To eliminate its dependence on oil imports, Brazil makes use of ethanol produced from cheap sugarcane. Maize-based ethanol is readily available in the USA, and that promotes the country's agricultural sector as well as improves its environmental performance [6].

Applying biofuel technologies, the European Union has several objectives at once: elimination of its dependence on oil imports, prevention of global warming, fulfillment of obligations under the Kyoto Protocol on emissions of carbon dioxide into atmosphere, and development of its agricultural sector.

The leading countries for bioethanol production in the European Union are Germany, Spain, France, Sweden, Italy, and Poland. At the request of the European community, the contents of alcohol in each gas tank should be 20% by 2020.

Literature review

Many researchers have focused on various issues of ethanol/gasoline blends engine performance. A.P. Muslinov (Kyrgyzstan), V.A. Orlov and V.I. Hlazunov (Lviv, Ukraine) have analysed the operating cycle of the carburetor engine in mountain environments. Yu.F. Hutarevych (Kyiv, Ukraine) has concentrated his research on effectiveness of alcohol additives in gasoline. However, operational characteristics of carburetor engines fueled with ethanol blends in mountain environments need further research.

The **objective** of this article is to identify advantages and disadvantages of using ethanol and ethanol-blended gasoline, to analyze operational performance of gasoline engine fueled with ethanol and its blends in mountain environments.

Materials and methods

As a rule, a biofuel is a fuel that is directly produced through biological processes from plant-derived materials (stems of sugar cane, potato, wheat, artichoke, maize). It may be also indirectly derived from cellulose and various organic wastes [7].

Biofuels are normally divided into three categories: solids (firewood, straw), liquids (ethanol, methanol, biodiesel) and gases (biogas, hydrogen). Internal combustion engines that provide outstanding drivability and durability can utilize liquid and gaseous biofuels. Liquid fuel is preferable not only because of the more voluminous heat of combustion, but also because it is the most compatible with existing power systems in engines.

Bioethanol can be used as a separate fuel; however, the most common use of ethanol fuel is by blending it with gasoline. The most common blends of bioethanol fuel are identified by letter «E» (from *ethanol*). Ethanol properties are summarised in table 1 and compared to base gasoline properties [8, 9].

Table 1. *Ethanol properties vs. gasoline properties*

Item	Base gasoline	Ethyl alcohol
Chemical formula	C_5-C_{10}	C_2H_5OH
Molecular weight, kg/kmol	95-115	46.04
Element, % mass:		
Carbon	84-86	52.2
Hydrogen	12-15	13.2
Oxygen	0	34.78
Density at 20°C, kg/m^3	725-780	789.3
Boiling point, °C	30-215	78.4
Freezing point, °C	-60	-114.1
Heat capacity, kJ/kg:		
Heat of evaporation	284-306	839.3
Heat of combustion	43500	26945
Vapor saturation pressure at 38°C, kPa	≤79.9	15.9
Viscosity, mm^2/c (at 20°C)	0.37-0.44	1.19
Conductivity, ohm/cm^2	$1 \cdot 10^{-14}$	$1.35 \cdot 10^{-9}$
Auto-ignition temperature	253-370	423
Flammable Range:		
Lower flammability limit	1.4	4.3
Upper flammability limit	7.6	19.0
Stoichiometric ratio – air : liquid	(14.7-15.5):1	9.0
Solubility in water at 20°C, %	none	highly
Octane number:		
Research octane number	92-98	108
Motor octane number	82-87	92

An important advantage of engines that work on bioethanol is their high anti-knock value or detonation stability (from Latin *detonate* – rattle) – the propagation of a flame at a high speed, close to the speed of sound in this environment.

Significant improvement in the quality of the performance of the engine that uses bioethanol motor fuel is achieved by adding to it a hydrocarbon fraction (p.k. – 60°C) – alkanes C_4-C_6, which considerably increases the pressure of saturated vapors. Multifunctionality of bio-ethanol fuel is based on the following principles:

1) maximum energy effectiveness of the fuel with optimal content of the compounds is achieved due to synergistic enhancement of their effect by intermediate organic compounds of the class of organic amines and their derivatives;
2) high effectiveness and low cost of bioethanol-blended motor fuel provide maximum profitability in the production of environmentally friendly fuels;
3) ethanol vapor dissipates faster than gasoline vapor;
4) ethanol fuel has a significantly lower level of toxins and does not contain carcinogenic substances;
5) ethanol vapor is less flammable than gasoline vapor due to a higher auto-ignition temperature;
6) ethanol offers a higher octane rating than gasoline.

Analytical calculations of technical and operational performance of gasoline engine were made for Engine 3M3 313.10 operating on gasoline, bioethanol, and two blends – 25% and 75% ethanol mixtures. The properties of gasoline, bioethanol and their mixtures selected and tested during this study are shown in table 2.

TABLE 2. *Chemical composition of gasoline, bioethanol and their blends*

Fuel	Elementary composition, mass fractions		
	C	H	O
Gasoline	0.855	0.145	0
75% gasoline + 25% ethanol	0.772	0.141	0.087
25% gasoline + 75% ethanol	0.605	0.134	0.261
Ethanol	0.522	0.130	0.348

Contemporary foreign and domestic studies prove that there is a certain relationship between the change in atmospheric pressure and temperature and elevation above sea level which is illustrated in table 3.

TABLE 3. *Basic environmental indicators depending on altitude above the sea level*

Altitude, m	Atmospheric pressure, kPa	Temperature, °C
0	101.3	20
1000	89.9	13.5
2000	79.5	7
3000	70.1	0.5

It is rather difficult to study the effect of individual environmental parameters (atmospheric pressure, ambient temperature, air humidity, etc.) in the mountains on the operation of internal combustion engines, in particular on their main dynamic, technical, operational and environmental characteristics. All these parameters effect the work of internal combustion engines in different ways; therefore, it is necessary to carry out analytical calculations in order to determine the magnitude of this effect and the direction of changing the main dynamic, technical, operational and environmental performance of cars on bioethanol fuel in mountainous conditions.

If the composition of the fuel is known, combustion heat of liquid and solid fuels is calculated by Mendeleev formula:

– upper:

$$Q_в = 339C + 1256H - 109(O - S) \quad (1)$$

– lower:

$$Q_н = Q_в - 25.12(9H + W), \quad \text{MJ/kg} \quad (2)$$

where *C, H, S, O, W* identify the content of respective elements and humidity, % mass.

The main technical and operational factors of automobile engines are the effective power N_e and effective specific fuel consumption g_e.

Effective power is the power of the engine delivered to the working machine directly or through power transmission. It is determined by equation:

$$N_e = \frac{P_e \cdot V_h \cdot n \cdot i}{30 \cdot \tau}, \text{ kW} \quad (3)$$

where:

P_e – stands for mean effective pressure in the engine cylinder, Pa,

V_h – for the working volume of the engine, m^3,

n – for the engine crankshaft rotation, min^{-1},

i – for the number of cylinders,

τ – for engine strokes.

Effective specific fuel consumption is calculated by equation:

$$g_e = \frac{3600}{Q_н \cdot \eta_e}, \quad \frac{\text{g}}{\text{kW} \cdot \text{hr}} \quad (4)$$

where η_e is effective engine efficiency.

Results

Comprehensive analyses were carried out to calculate the value of the change in engine power and effective specific fuel consumption g_e and its dependence on the rotational speed of the engine crankshaft n. The main results of analytical calculations of technical and operational parameters of Engine ZMZ-513.10 fueled with tested ethanol and ethanol-blended gasoline are summarized in figures 1-8.

At the final stage of our study, the car engine was tested at an altitude of 1000 m, since most of the settlements in the Carpathian mountains are mainly located at this altitude. The data obtained are as follows:

1. The power of the engine on the tested fuels varies depending on ethanol increase in the blend within the range studied, respectively:
   - 78.767 kW – for pure gasoline engine;
   - 79.844 kW – for the mixture of 75% gasoline and 25% ethanol, the power of the engine increasing by 1.367% compared to pure gasoline;
   - 82.942 kW – for the mixture of 25% gasoline and 75% ethanol, the power of the engine increasing by 5.36% compared to pure gasoline;

– 85.21 kW – for pure ethanol, the power of the engine increasing by 8.18% compared to pure gasoline.

2. The specific fuel consumption of the tested engine is also different, namely:
   – 321.363 g/(kW·hr) – for pure gasoline engine;
   – 351.84 g/(kW·hr) – for the mixture of 75% gasoline and 25% ethanol, specific blend consumption increasing by 9.484% compared to pure gasoline consumption;
   – 433.048 g/(kW·hr) – for the mixture of 25% gasoline and 75% ethanol, specific blend consumption increasing by 34.754% compared to pure gasoline consumption;
   – 490.361 g/(kW·hr) – for pure ethanol, specific ethanol consumption increasing by 34.754% compared to pure gasoline consumption.

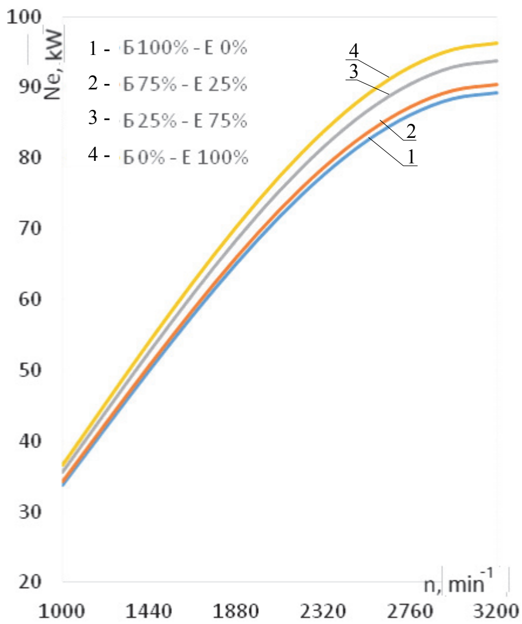

Figure 1. *Dependence of effective power on the on the number of engine revolutions at an altitude of 0 m*

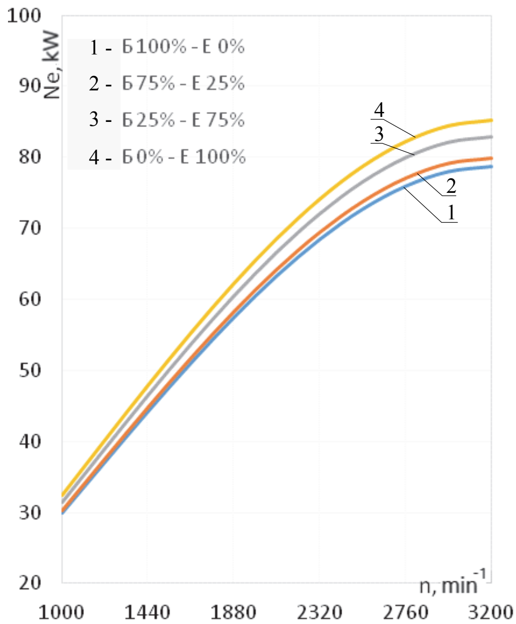

Figure 2. *Dependence of effective power on the on the number of engine revolutions at an altitude of 1000 m*

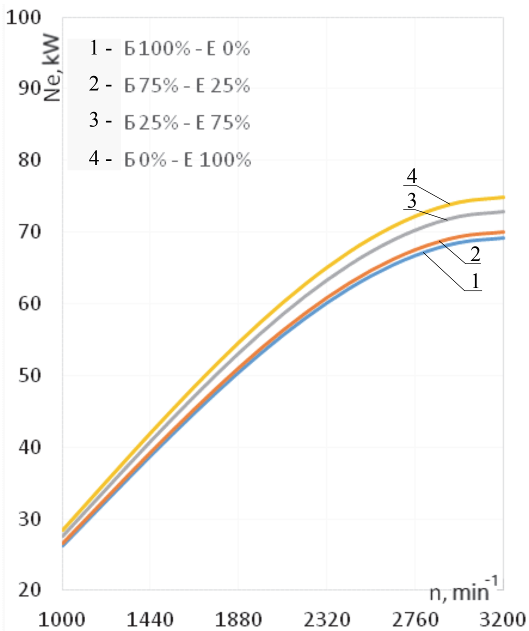

Figure 3. *Dependence of effective power on the on the number of engine revolutions at an altitude of 2000*

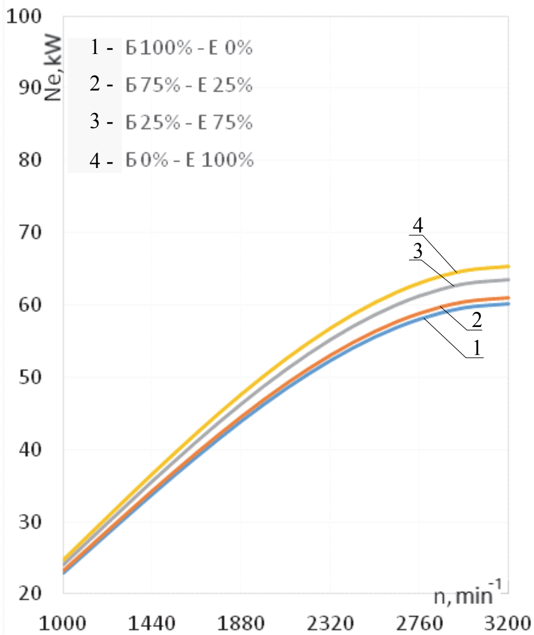

Figure 4. *Dependence of effective power on the on the number of engine revolutions at an altitude of 3000 m*

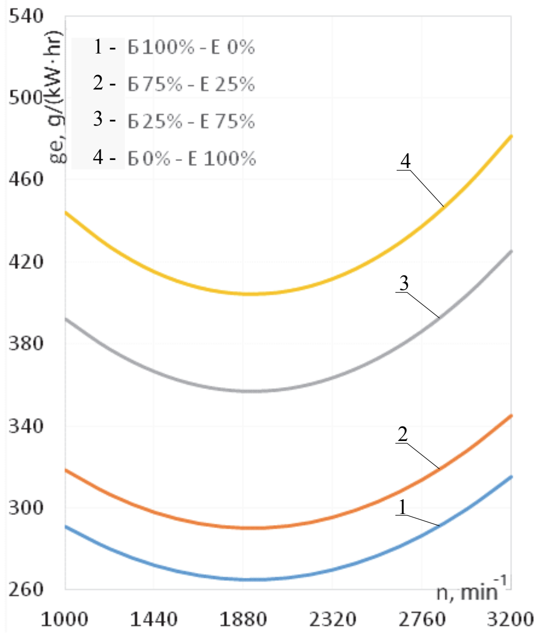

***FIGURE 5.** Dependence of the specific fuel consumption on the number of engine revolutions at an altitude of 0 m*

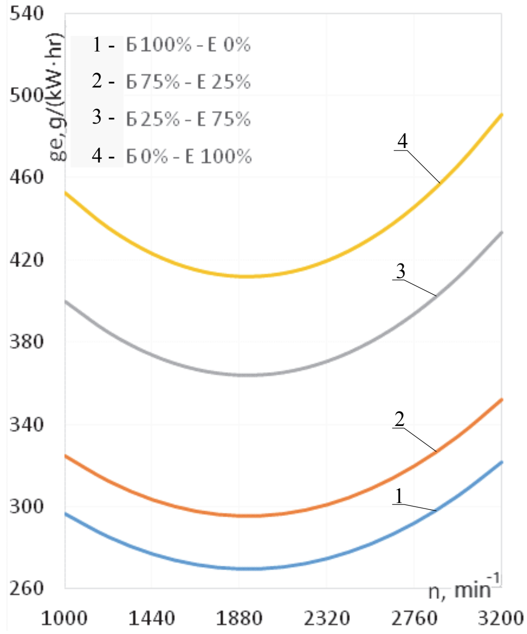

***FIGURE 6.** Dependence of the specific fuel consumption on the number of engine revolutions at an altitude of 1000 m*

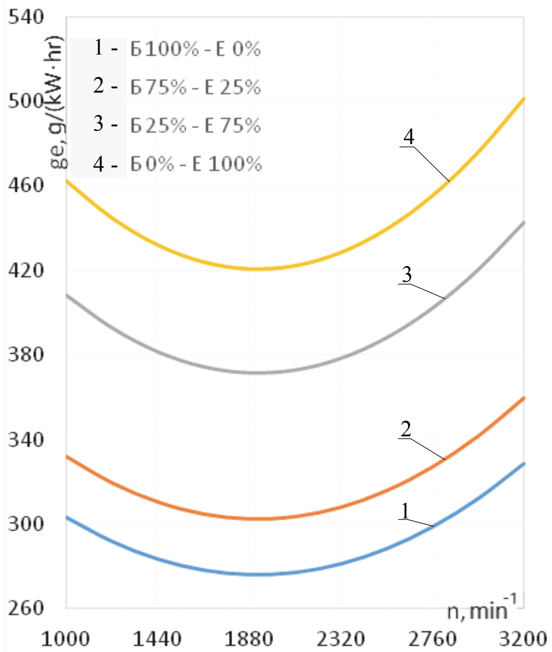

***FIGURE 7.** Dependence of the specific fuel consumption on the number of engine revolutions at an altitude of 2000 m*

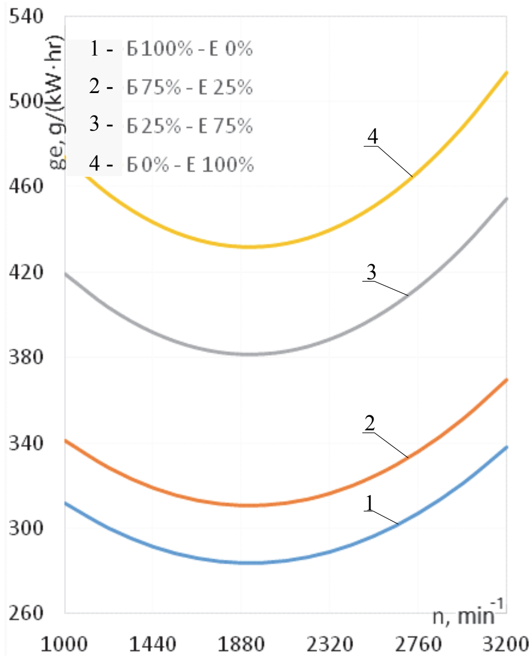

***FIGURE 8.** Dependence of the specific fuel consumption on the number of engine revolutions at an altitude of 3000 m*

Conclusions

Analytical calculations prove that the use of pure bioethanol and its blends with gasoline effects the engine power significantly, but the transition to biofuels and its mixtures will increase hourly fuel consumption and, respectively, effective specific fuel consumption.

When planning the operation of the rolling stock of any motor transport company as well as the operation of cars in mountainous conditions, it is necessary to take into account that fuel consumption increases with height. The use of biofuels (bioethanol) makes it possible to significantly reduce the content of harmful substances in exhaust gases. Besides, a striking advantage of ethanol over other fuels is that it does not cause pollution to the Carpathian environment, which is the main tourist attraction.

When operating the car at different heights, the performance of the engine fueled with different gasoline-ethanol mixtures improves considerably with the increase of the percentage of ethanol in the blend. It favourably effects the engine power and specific fuel consumption.

This study will serve as the basis for further research of some other parameters of internal combustion engines running on standard gasoline and ethanol-blends in mountain conditions. Among the promising directions of research are changes of technical and operational parameters, filling indicators, residual gas coefficient, combustion process peculiarities, and some others.

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