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BIOGAS AS AN ALTERNATIVE FUEL FOR AUTOMOTIVE TRANSPORT IN MOUNTAIN AREAS

Abstract: *The importance of the problem of effective use of traditional energy sources and the search for alternative resources is beyond doubt. However, nowadays Ukraine does not fully use the potential of low-calorie gases, in particular, biogas, produced by agriculture and industry in large quantities. The number of available domestic installations for the disposal of this gas is negligible although a great number of developed countries have thousands of such facilities.*

One of the most advantageous sources of energy is biogas produced *out of biological waste from communal and agricultural dumps – landfill sites for waste disposal. It is meanwhile burnt in flares or emitted into the atmosphere contaminating it heavily. The level of biogas used as a fuel in automotive internal combustion engines is very low. However, replacing gasoline with biogas results in engine power reduction and fuel consumption increase. This should be taken into account when operating cars in mountainous areas where atmospheric pressure and temperature are lower.*

Keywords*: biogas, efficiency, the heat of combustion, atmospheric pressure, temperature, power, specific consumption.*

Introduction

Biogas is a gas formed by microbiological decomposition of organic waste in landfills, swamps, sewage systems, and the like.

Today, the share of renewable energy in the world energy balance is negligible – it accounts for only 14%, with biomass contribution being 1.2%. Yet, as practice proves, even slight fluctuations in energy resource markets result in significant energy price increases. Therefore, the role of alternative energy in the markets will only grow. The world biomass energy is up to 13% in the structure of alternative energy. According to recent research, by 2040 the share of renewable energy sources will reach 47.7% and biomass will contribute to 23.8% [1].

The problem of mountainous condition impact on performance indicators of automobile engines running on biogas in Ukraine and in the world is not paid enough attention to.

Exploitation of cars on mountain roads in the Carpathian region is rather difficult at altitudes of 1000÷2000 m above sea level with ascents and descents reaching 12%, the length of sections ranging from 10 km to 15 km.

The higher is the elevation above the sea level, the lower is atmospheric pressure, air density, and temperature, which affect the filling of the car engine cylinder. Concurrently, air leakage and low speeds on steep climbs result in reducing the engine cooling rate. At the same time, the work of engines on the combustible mixture in question and the movement for the most part on the lower gears leads to engine overheating, and the boiling temperature of the coolant gets reduced in the mountains.

Analysis of modern foreign and domestic data

According to the data presented in [2], there is a certain dependence of the change in atmospheric pressure and ambient temperature on the altitude which is shown in table 1.

TABLE 1. *Basic environmental indicators depending on altitude*

Position	Altitude, m	Atmospheric pressure, kPa	Temperature, °C
1	0	101.3	20
2	1000	89.9	13.5
3	2000	79.5	7
4	3000	70.1	0.5

The **purpose** of the article is twofold: 1) to analyze the possibility and features of the use of biogas as a fuel for internal combustion engines in mountainous conditions; 2) to investigate the influence of separate parameters of the environment in mountainous conditions on the work of internal combustion engines, their technical and operational indicators.

International experience

Biogas technologies are developing at a fast pace. According to the International Bioenergy Journal, 80% of the biogas potential is contained in agricultural raw materials and 10÷11% in industrial and municipal waste. Now Germany ranks first in Europe in the number of biogas plants: in **2010** there were more than 9000 of them. 7% of the biogas produced by these plants is supplied to gas pipelines, the rest is used for the needs of the producer. Denmark is a leader in terms of biogas application. There this type of fuel accounts for almost 20% of the total energy consumption of the country.

Twelve European countries (Austria, Czech Republic, Germany, Denmark, Finland, Sweden, Great Britain, Italy, Iceland, Hungary) use biomethane to fuel motors (including its blend with natural gas), as well as to produce heat [3].

There are few examples of biogas technologies in Ukraine. Several biogas projects at Solid Waste Landfills (SWL) in Mariupol, Lviv, Kremenchug, Lugansk, Kyiv, as well as at Bortnitsky Sewage Treatment Plant of (Kyiv). The project implemented by the LNC Company at Kiev landfill No. 5 proved to be the most successful: the site is equipped with five TEDOM diesel biogas engine with an installed capacity of 177 kW. A vivid example of successful biogas projects concerning the use of biogas for internal combustion engines is the biogas installation "Polygon TPV in the village of Rybne" near the city of Ivano-Frankivsk. 18 boreholes were drilled for biogas production from the landfill, and two gas-fired 330 kV plants were installed to generate electricity. Unfortunately, examples of successful biogas use for automotive internal combustion engines, apart from primitive farmer projects, can be hardly found in Ukraine.

Compared with traditional fuels, biogas has the following advantages:

- It is made from biological raw materials, hence its production and incineration are part of the natural cycle of carbon, which does not cause gas accumulation in the atmosphere and does not result in the greenhouse effect. Environmental damage from organic waste collection systems is decreasing. An ecologically close energy system is provided.
- Biogas is a renewable energy source; in fact, it will never get exhausted if compared with petroleum which is anticipated to get exhausted in no more than 50 years [4].
- Biogas is produced close to the consumer, the raw material for its production is also located not far from the factories and there is no need to transport gas over long distances.

The average component composition of biogas is given in table 2.

***Table 2.** Component composition of biogas*

No.	Component	Content, % volume
1	Methane (CH_4)	50÷75
2	Carbon dioxide (CO_2)	25÷50
3	Hydrogen (H_2)	0÷1.0
4	Hydrogen sulfide (H_2S)	0÷3.0
5	Nitrogen (N_2)	0÷10.1
6	Oxygen (O_2)	0÷2.0

Availability of biogas in hydrogen sulfide is a rather negative factor since hydrogen sulfide reacts with most metals and can cause corrosion of some parts of internal combustion engines, reservoirs, and tanks. Therefore, the issue of cleaning biogas is of great importance.

In comparison with traditional automobile fuels, a major disadvantage of biogas is a low concentration of energy from its combustion, which leads to a decrease in the efficiency of the engine, effective power, and increased fuel consumption.

Knowing the componential composition of biogas by the Mendeleev formula, we can calculate the biogas combustion heat Q_H:

$$??? \; Q_H = 128 \cdot CO + 108 \cdot H_2 + 234 \cdot H_2S + 339 \cdot CH_4 + 589 \cdot C_nH_m \quad [kJ/m^3] \tag{1}$$

where $CO, H_2, H_2S, CH_4, C_nH_m$ are amounts of individual components in gaseous fuel, % volume under normal conditions.

According to formula (2), combustion heat of gas mixtures is calculated as

$$Q_{n.c.} = \frac{Q_H \cdot \eta}{1 + \alpha L_0} \tag{2}$$

where:

η – a coefficient of combustion completeness;

L_0 – the theoretically calculated volume of air necessary to combust 1 m³ of fuel under normal conditions.

Our calculations show that when the air excess coefficient α = 1, the values of the lower heat for the Opel-Vectra engine are as follows:

- for the gas-air mixture – $Q_H = 3739$ kJ/m³,
- for the air-gas mixture – $Q_H = 3404$ kJ/m³,
- for the biogas-air mixture (with CH_4 content = 62%) – $Q_H = 2168$ kJ/m³.

Compared with the standard fuel, reduction of the specific heat of combustion of 1 m³ of the combustible mixture with natural gas CH_4 is 8.7%, of biogas is 42.1%, and of the mixture of biogas and 30% CH_4 is 15.25%. That is, one of the options for improving the performance of internal combustion engines is to mix natural gas with biogas. The lower heat of combustion of such a mixture varies according to the graph shown in figure 1.

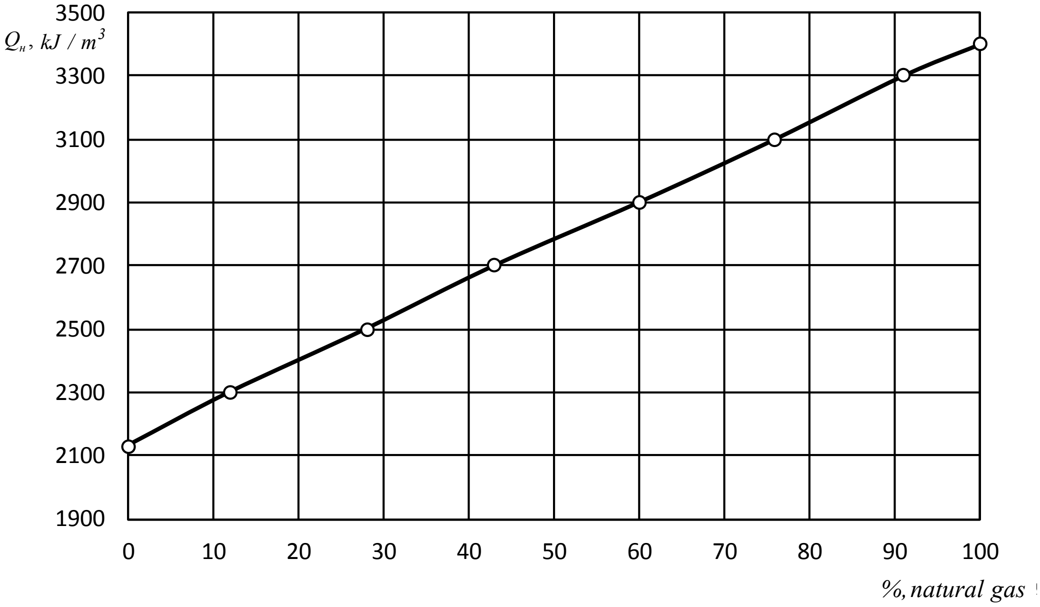

FIGURE 1. *Lower heat of combustion of gas mixtures of CH_4 and biogas*

Discussion

The research was carried out on the engine ZMZ-5234 and ZIL-130. The necessary calculations were made by using the software complex designed for calculation and optimization of internal combustion engines "Diesel-PC" [5] was used.

The main technical and operational indices of automobile engines are the effective power N_e, torque M_k, specific effective g_e and hourly fuel consumption G_T

$$N_e = \frac{P_e \cdot V_h \cdot n \cdot i}{30 \cdot \tau} \text{ [kWt]} \tag{3}$$

where

V_h – the operating volume of the engine, l;

n – a number of revolutions, rpm;

i – a number of cylinders;

τ – a stroke of the engine.

$$M_k = \frac{3 \cdot 10^4 \cdot N_e}{\pi \cdot n} \text{ [H·m]} \tag{4}$$

Specific effective fuel consumption is

$$g_e = \frac{G_T}{N_e} \left[\frac{\text{kg}}{\text{kWt} \cdot \text{hr}}\right] \tag{5}$$

where G_T is hourly fuel consumption, g/h.

As a result of analytical studies, the graphs of the dependence of the change in effective power and on the effective specific biogas consumption rate from changes in temperature and changes in atmospheric pressure of the environment were obtained.

These dependences are shown in figures 2-5.

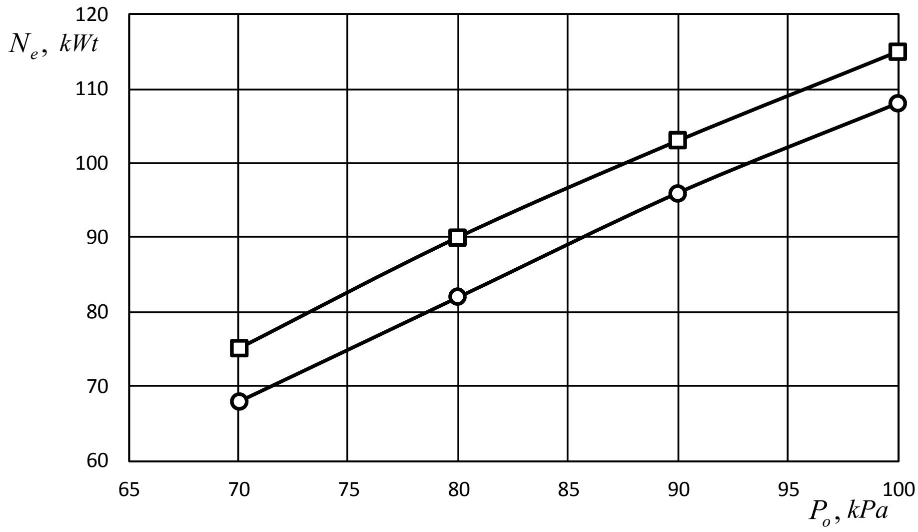

Figure 2. *Dependence of the effective power change of Engine ZMZ-5234.10 on atmospheric pressure*

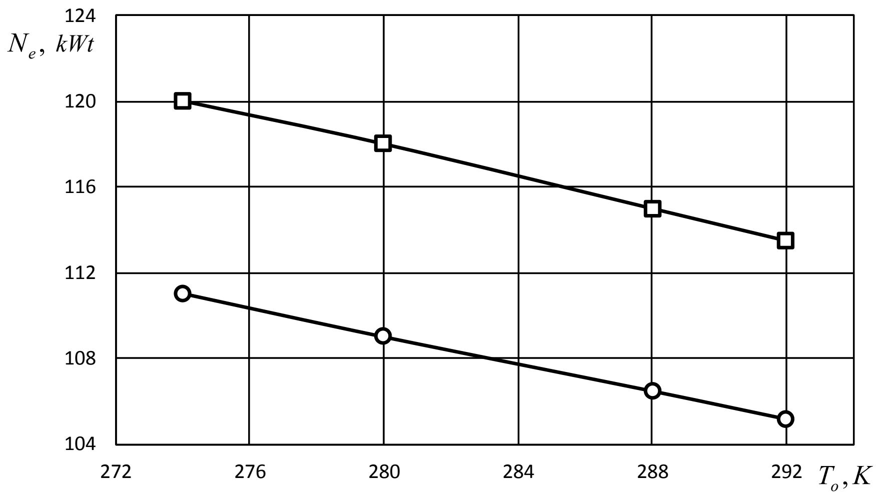

Figure 3. *Dependence of the effective power change of the Engine ZMZ-5234.10 on the temperature change of the environment*

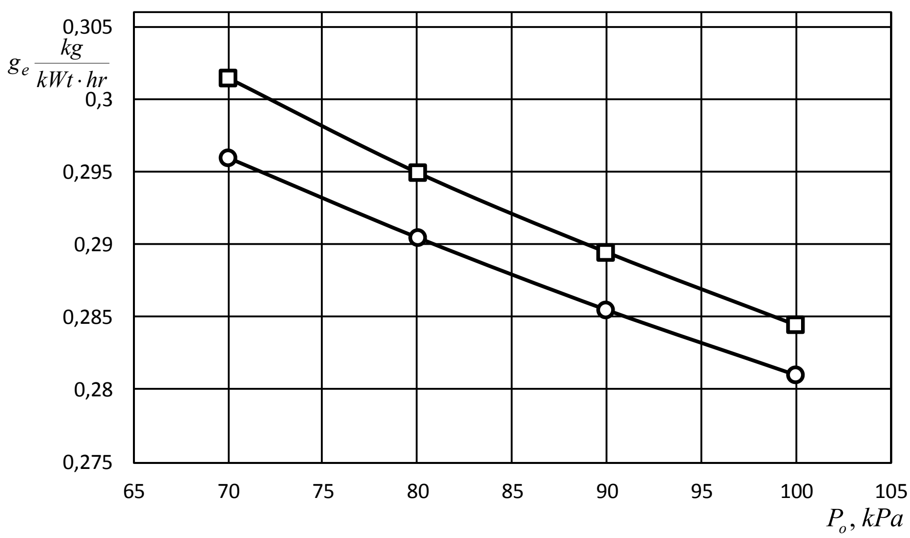

Figure 4. *The change in the specific effective fuel consumption of Engine ZMZ-5234.10 on the atmospheric pressure change*

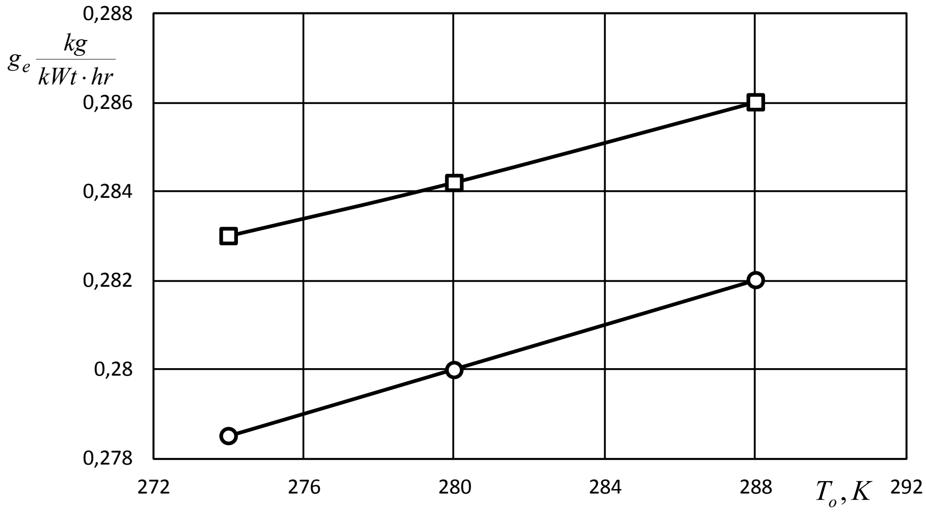

***FIGURE 5.** The change in the specific effective fuel consumption of Engine ZMZ-5234.10 on the ambient temperature changes*

As the study proves, when using biogas as automotive fuel in mountainous conditions with lower atmospheric pressure, the effective power is reduced by 6÷9% compared with gasoline; and the specific effective fuel consumption is increased by 7.3-7.5% depending on the size of the reduced pressure. By reducing the ambient temperature, the effective engine power is reduced by 14÷16% and the specific effective fuel consumption is increased by 14÷20%. The impact of these factors can be reduced by adding natural gas to biogas. How it affects the specific effective fuel consumption in engines is shown in figure 6.

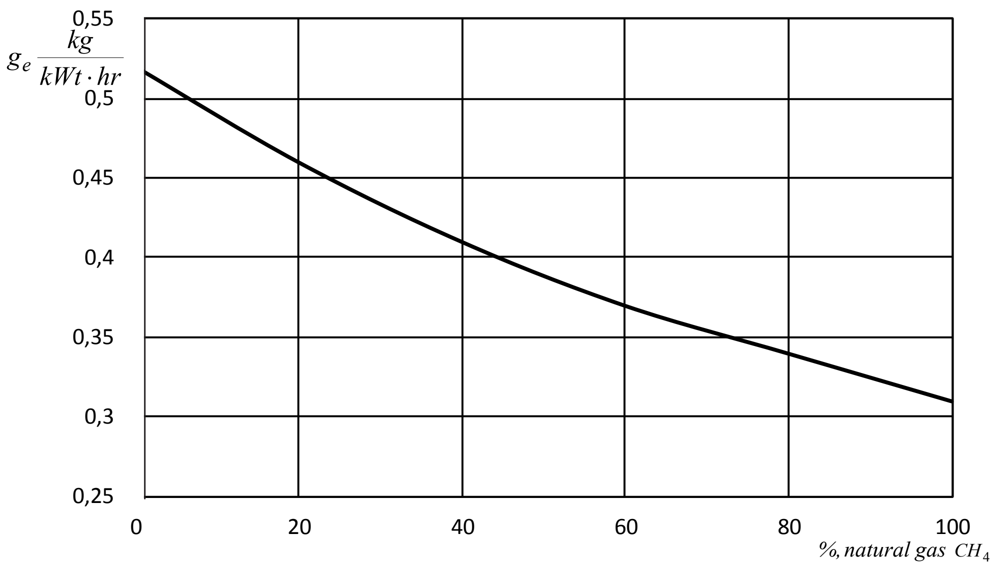

***FIGURE 6.** Changes of the specific fuel efficiency when adding natural gas*

Conclusions

1. The use of biogas for internal combustion engines in mountain conditions may partially solve the problem of fuel shortages. Ukraine has the necessary reserves to do this.
2. Since the lower heat of biogas combustion is by (40÷45)% less than that of conventional petroleum fuels, the capacity and specific effective consumption of fuel used by cars running in mountain conditions are significantly changing. Depending on the ambient temperature, the power is reduced

by 14÷16%, and the specific fuel consumption is increased by 14÷20%. Depending on the altitude, the power is reduced by 6÷9%, and fuel consumption is increased by 7.3-7.5%.

3. It is possible to improve the technical and operational performance of internal combustion engines by blending natural gas and biogas.

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