Taras DYKUN, Lubov HAIEVA

Fedir KOZAK, Yaroslav DEMIANCHUK

Ivano-Frankivsk National Technical University of Oil and Gas, Ukraine

THE ANALYSIS OF CERTAIN FEATURES OF WORKING PROCESS OF INTERNAL COMBUSTION ENGINE THAT WORKS ON BIOGAS FROM DISPOSAL SITES

Abstract: *The importance of providing humankind with cheap energy through alternative ways has significantly increased in recent years. One of the areas is the production and usage of biogas. Nowadays, the potential of LCV gases is poorly implemented. These gases are produced in large quantities by agriculture and industry. The number of existing domestic installations for the disposal of this gas is insignificant, although in most developed countries there are hundreds and thousands of such units.*

One of the most promising sources of energy is the biogas from disposal sites, which is now polluting the atmosphere or is burned in flares. Another direction of biogas usage as a fuel in internal combustion automobile engines is also lowly developed. Because of the instability of the biogas composition, the working process of the engines has certain features that should be taken into account. In particular, an important criterion that affects the composition and, accordingly, the toxicity of the exhaust gases of the engines, is the excess air ratio for the fuel mixture.

Keywords: *biogas, disposal sites, efficiency, waste gases, combustion products, excess air ratio, methane content.*

Introduction

Ukraine has limited resources for production of fuel for the internal combustion engines from oil, therefore it is urgent to search for alternative types of automobile fuel. Usage of biogas from landfills and secondary products of stockbreeding is one of the sources for this. There is great potential for this in Ukraine. At present, a particle of biomass in the primary energy supply is only 1.4% or 1695 thousand tons for energy unit (IEA Statistics Ukraine) [1].

According to projections a particle of alternative energy sources by 2040 will be 48%, of which 24% will account for biomass [3]. Biomass is derived from plants or animals and is available on a renewable basis. It includes timber and crops, animal, and plant waste, municipal organic waste, and more. Biogas production is the result of anaerobic digestion of organic matter – that is, the natural process of microbial decomposition of organic mass in a humid environment in the absence of oxygen.

Combustible gas is formed as a result of biomass fermentation, which includes methane (50÷70%), carbon dioxide (25÷50%), water vapour (2÷4%), hydrogen (0÷1%), ammonia, and hydrogen sulphide. Average composition of biogas in the study of landfills of solid household waste are shown in Table 1.

Table 1. *Biogas components in the study of landfills of solid household waste (Kyiv)*

Landfills	CH_4	CO_2	O_2	N_2	H_2S	H_2O
No. 1	64.1	32.2	–	1.6	0.07	2.0
No. 2	61.2	29.9	1.38	6.0	–	1.4
No. 3	54.1	39.5	–	4.9	–	1.51
No. 4	67.1	20.4	4.11	6.2	–	2.14
No. 5	70.6	23,4	–	3.45	–	2.56

The main component of biogas is, of course, methane. Biogas composition depends on the substrates and the fermentation process.

Foreign experience

Purified biogas can be used as a fuel for vehicles. The Volvo and Scania concern produces buses powered by biogas engines. These buses are used in the cities of Bern, Basel, Geneva, Lucerne and Lausanne. According to the forecasts of the Swiss Gas Industry Association, by the end of 2020, more than 10% of Switzerland's motor vehicles will be powered by biogas. In 2009, the City of Oslo transferred 80 city buses to biogas. Up to 400 buses will be transferred to biogas in the near future. Among industrialized countries, Denmark holds the leading position in the production and usage of biogas – 18% of its total energy balance. According to IRENa estimates, less than 5% of biogas production potential is used in Ukraine – 49.5 million m^3 of biogas from agricultural waste and 33 million m^3 from solid waste landfills were used in 2014 [3].

The question of analysis of influence of mountain conditions on performance of ICE in Ukraine has received little attention, and their studies with usage of biogas in mountain conditions have hardly been conducted. The operation of vehicles in the mountains at altitudes of 1000÷2500 m is quite relevant, especially for the Carpathian region. At these altitudes, atmospheric pressure, air density, and temperature decrease, it leads to a deterioration of filling of the engine cylinders and, consequently, decreasing in technical and operational and economic performance of engine. Operation of vehicles on mountain roads also leads to changes in the coefficient of excess air and enrichment of combustible mixture, which affects the specific fuel consumption and, of course, the effective power.

Purpose and problem statement

The article analyses conditions of filling the internal combustion engine cylinders working on biogas from dumps and secondary products of stockbreeding and standard fuel operating them in mountain conditions.

Research results

According to the data given in the literature [1, 2, 7], the dependence of environmental parameters on altitude above sea level is shown in Table 2. Since the operation of vehicles in the Carpathians is mainly carried out at altitudes of 1000÷3000 m, we are considering just these parameters.

TABLE 2. *Dependence of basic environmental parameters on altitude*

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

Perfection of the process of inlet of fresh mixture in the ICE is estimated by the filling coefficient η_v.

In general

$$\eta_v = \frac{G_F}{G_T} = \frac{G_F}{V_h \cdot \rho_o} \tag{1}$$

where:

G_F – mass of fresh charge in kg, which actually entered the cylinder;

G_T – theoretically possible mass of charge that can enter the cylinder;

V_h – working cylinder capacity, m^3;

ρ_o – density of fresh charge, kg/m^3

$$\rho_o = \frac{P_o}{R_s \cdot T_o} \tag{2}$$

where:

R_s – specific gas constant of air, R_s = 287 J/kg·K;

P_o, T_o – pressure and ambient temperature, respectively, Pa and K.

Using the equation of state and considering the measure of compression $\varepsilon = \frac{V_a}{V_{cc}}$, and the residual gas coefficient

$$\gamma_g = \frac{M_{rg}}{M_m} \tag{3}$$

where:

M_{rg} – mass of residual gas in cylinder of engine;

M_m – mass of the fresh mixture entering the cylinder;

V_a – total volume of the engine cylinder, m^3;

V_{cc} – volume of the combustion chamber.

We will get

$$\eta_v = \frac{\varepsilon}{\varepsilon - 1} \cdot \frac{P_a \cdot T_o}{\left(T_o + \Delta T + \gamma_g T_g\right) P_o} \cdot \varphi_1 \tag{4}$$

where:

ΔT – fresh charge heating from the exhaust manifold, K;

T_g – temperature of residual gases, K;

φ_1 – purge and recharge coefficient. For 4 stroke engines in the absence of supercharging can be taken $\varphi_1 = 1$.

The engine filling coefficient at altitude and under normal conditions will be determined by formulas

$$\eta_{va} = \frac{G_{Ra}}{G_{ma}} \tag{5}$$

$$\eta_v = \frac{G_R}{G_m} \tag{6}$$

where:

G_{Ra}, G_R – the actual amount of air entering the cylinder at altitude and given under real conditions;

G_{ma}, G_m – theoretically possible amount of air that can enter the cylinder at altitude under normal conditions.

As air flow varies proportionally to pressure changing and inversely proportional to the square root of its temperature and

$$G_{Ra} = V_h \cdot \rho_a \tag{7}$$

$$G_R = V_h \cdot \rho_o \tag{8}$$

where ρ_a, ρ_o air densities at altitude and under normal conditions.

We will get

$$\eta_{va} = \eta_v \cdot \sqrt{\frac{T_a}{T_o}} \tag{9}$$

where T_a, T_o are the temperatures of the mixture at altitude and under normal conditions.

According to Table 1 and formulas (1)-(9) calculation of influence of environmental parameters on the filling coefficient of the engine ZMZ-52.34.10 has been done on standard fuel and on biogas from livestock products and landfills.

The software "Diesel – PC" for calculations and optimization of ICE was used for calculations [2].

Graphical dependency of the filling coefficient with respect on ambient temperature and pressure is shown in Figure 1 and Figure 2.

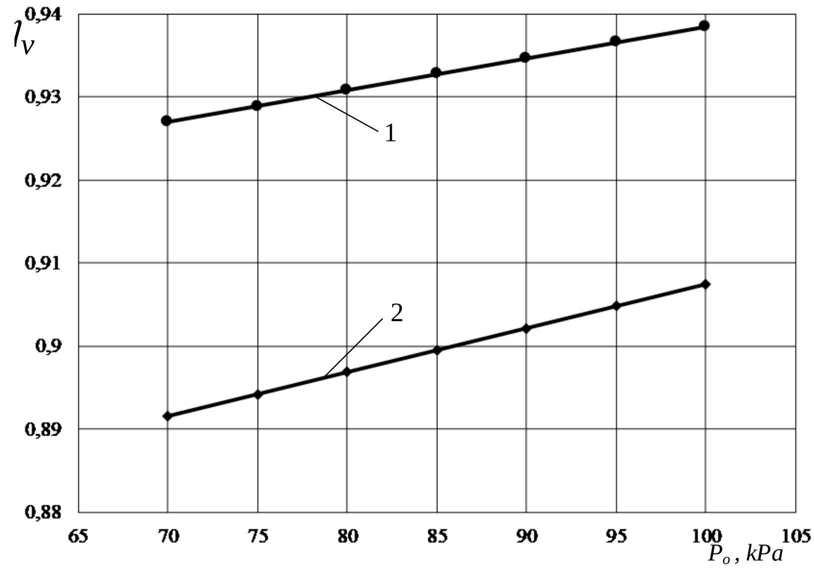

***FIGURE 1.** Analytical dependence of changing of the engine fill coefficient with respect on ambient temperature: 1 – standard gasoline; 2 – biogas*

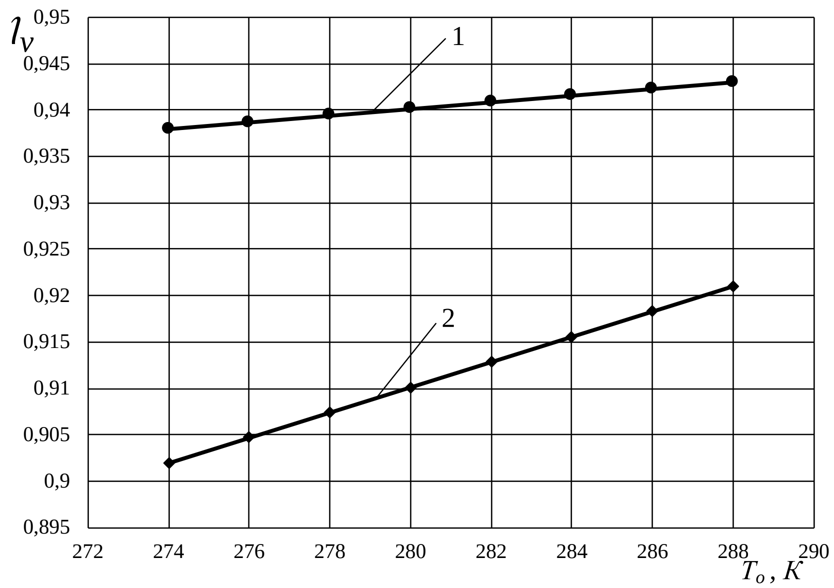

***FIGURE 2.** Analytical dependence of changing of the filling coefficient of the engine with respect on atmospheric pressure: 1 – standard gasoline; 2 – biogas*

In general, the filling coefficient is affected by: compression ratio, pressure and temperature of the inlet end, charge heating temperature ΔT, charge and purification coefficient, pressure and ambient temperature P_o, T_o, residual gas coefficient γ_g. Since these parameters are interrelated it is advisable to consider the totality of their effects depending on the engine mode.

Measure of compression ε

When other parameters remain unchanged compression ratio does not significantly affect the fill coefficient. In fact, as ε increases, other parameters change (the coefficient and temperature of the residual gases decrease, and the heating of the mixture improves). For highly compressed engines only, the fill coefficient is slightly higher.

Pressure at the end of the inlet P_a

P_a depends on the resistance of the inlet system (design and arrangement of valves, the presence of local resistances, the quality of the surface treatment of the walls of the inlet system, etc. and the average charge rate, the mode of operation of the engine). As the average speed increases, therefore η_v decreases. It should be taken into account when designing the intake system, when there is a desire to increase it. In general, with increasing P_a, the filling coefficient increases significantly.

The temperature at the end of the inlet T_a

$$T_a = \frac{T_o + \Delta T + \gamma T_r}{1+\gamma}, \text{ K}$$

The temperature at the end of the inlet is mainly influenced by the ambient temperature T_o, charge heating ΔT and the temperature of the residual gases. ΔT depends on the relative position of the inlet and outlet manifolds and can be accepted 0÷40°C (at one-sided arrangement ΔT to 40°C, at equilateral arrangement ΔT = 0). For gasoline engines the dependence $\eta_v = f(\Delta T)$ is shown in Figure 3.

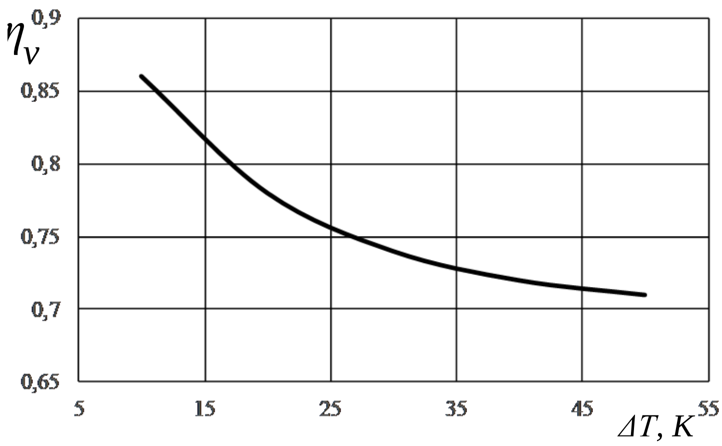

FIGURE 3. *Dependence of the engine filling coefficient on charge heating*

As $\Delta T - T_a$ increases, η_v also increases. It should be noted that at large values of T_a the charge density changes, which also affects the fill coefficient.

Residual gas pressure P_g

As P_g increases, amount of residual gas in cylinders increases and the filling coefficient decreases. The pressure of P_g depends on resistance of exhaust system and the rate of gas leakage.

Temperature and coefficient of residual gases T_g i γ_g

Formula (4) shows that product $\gamma_g T_g$ is affected by the filling coefficient. Assuming that the residual gas and air heat dissipation rates are not significantly different, then T_g has little effect on η_v since the fresh mixture expands from heating to the extent that the residual gases are compressed by the heat transfer of the fresh incoming mixture. The filling coefficient can be increased by blowing the combustion chamber (changing P_g and T_g).

As a result of analytical researches we obtained graphs of dependence of the change in the effective power and the effective specific consumption of biogas on the change of temperature and change of the atmospheric pressure of the environment.

These dependencies are shown in Figures 4, 5.

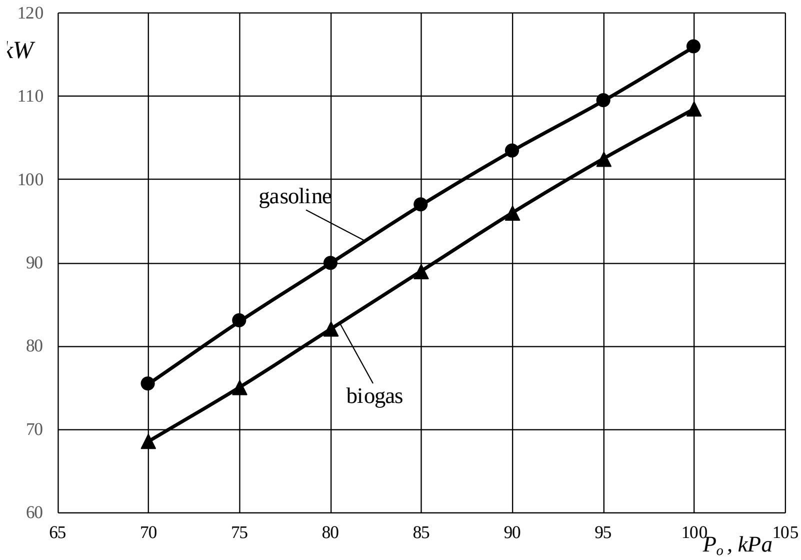

***FIGURE 4.** Dependence of change of effective power of the engine ZMZ-5234.10 on atmospheric pressure*

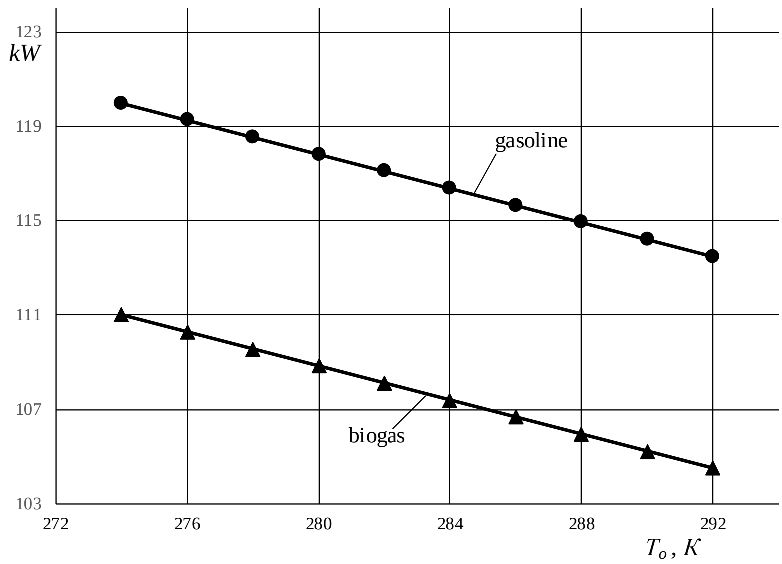

***FIGURE 5.** Dependence of change of effective power of the engine ZMZ-5234.10 on change of ambient temperature*

As can be seen from above researches, using biogas as a motor fuel in mountain conditions with reduced atmospheric pressure decreases compared to standard gasoline effective power by 6÷9% and increases the specific effective fuel consumption by 7.3÷7.5%, depending on the magnitudes of pressure reduction. As ambient temperature decreases effective power of engine decreases by 14÷16% and increases the specific fuel efficiency by 14÷20%. The impact of these factors can be reduced by the addition of natural gas to biogas.

Conclusions

Analysing filling of cylinders of the combustion engine operating in mountain conditions we can make the following conclusions:

- at increased height at which the engine is operating values of the temperature and pressure of the fresh mixture inlet to engine cylinders differ significantly from these parameters at sea level;
- when the environmental pressure is reduced by 35 kPa the cylinder filling coefficient of the engine is reduced from 0.895 to 0.81, that is, 9.5%;
- when the ambient temperature is reduced from 290 K to 272 K the engine filling coefficient decreases from 0.995 to 0.925, that is, 7%;
- decreasing of air density and lowering of temperature leads to decreasing of filling of engines, which, in turn, leads to a deterioration of technical and operational performance, the decrease of effective power, the effective specific fuel consumption, etc. The main cause of these processes is the deterioration of fuel combustion conditions.

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