Taras DYKUN, Lubov HAIEVA
Fedir KOZAK, Yaroslav DEMIANCHUK

IFNTUOG, Ivano-Frankivsk, Ukraina

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*

General information

Biogas is a gas produced from organic waste (food waste, dumps) with the help of bacteria and has a composition similar to natural gas: it is methane, hydrogen sulfide, carbon dioxide, water vapor, and the like. Biogas has a number of advantages over natural gas, namely:

- biogas is produced from raw materials, therefore, its production and incineration are part of the natural cycle of carbon, which does not lead to the accumulation of natural gas in the atmosphere and the greenhouse effect;
- biogas is a renewable energy source, which will never exhaust. While natural oil and gas according to the calculations will last no more than 50 years;
- biogas is produced close to the consumer, the raw material for its production is also located close to the factories. No need for long distance gas transportation.

The very process of gas formation is the so-called *methane fermentation*. Its essence lies in anaerobic fermentation (no air access), which occurs because of the life of microorganisms and is accompanied by a number of biochemical reactions. The actual process of biogas formation itself consists of two stages: the first is microorganisms splitting biopolymers into monomers; the second is the processing of monomeric biomolecules by microorganisms. At present, the share of renewable energy sources (RES) in the world energy balance is small – about 14%, and the contribution of biomass – about 1.8%. However, as practice shows, even small fluctuations in energy markets cause large price changes. This suggests that the role of alternative energy in the markets will only grow. In the structure of alternative energy in the world, the biomass energy contains up to 13%. According to scientists' predictions, the share of renewable energy sources will reach 47.7% by 2040 and the contribution of biomass will be 23.8%.

The ecological effect of biogas production is the ecologically safe processing of organic waste with the development of integrated technologies for biomass utilization due to methane fermentation. In biogas plants, primarily, animal excrements and reproducible raw materials, primarily, are various organic waste of the agro-industrial complex, which are rich in cellulose and other polysaccharides. However, biogenic waste from the food industry and household waste are becoming increasingly important. In biogas production, primary raw materials are used, which was not used before and only contributed to the contamination of the environment. Such organic substances are used either alone or in combination (substrates) with other organic substances. Thus, you can create programs for a specific location that allows the rational production and usage of biogas.

The aim of the research

The aim of the research to determine the advantages and disadvantages of biogas usage from disposal sites as vehicles fuel; to analyze the characteristics of the waste gases' compound of internal combustion engines (ICE), based on biogas; investigate its impact on the environment.

Foreign experiences

In most developed countries, recycling of waste dumps in biogas plants is more often used for the thermal and electric energy production. The energy produced in this way, on average, makes about 3-4% of the total energy consumption in the countries of the European Union (EU). For example, Finland, Sweden and Austria legislatively promote the use of biomass energy at the state level. The share of energy produced from biomass in these countries reaches 15-20% of the energy consumed in general.

Today, the European biogas plants market remains about $ 2 billion; it is predicted to grow up to 25 billion by the year of 2020. The use of electricity and heat from biomass anaerobic digestion is most common in Austria, Finland, Germany, Denmark and the UK.

In Germany today there are more than 9,000 anaerobic digestion plants, of which about 2000 large and about 7,000 averages. In the future, 10-20% of the natural gas used in the country can be replaced by biogas. By 2020, an increase in the number of installations is expected to reach 20,000.

In Austria, there are more than 120 installations with reactor volumes of over 2000 m^3 each; about 25 plants are under construction and planning.

Denmark is leading the way in using biogas, where this kind of fuel provides nearly 20% of the energy consumption of the country at present.

The biogas market in the USA is developing much slower than in Europe. For example, despite the presence of a large number of farms, there are only about 200 biogas plants processing agricultural waste on the territory of the country. Since 2002, the Chinese government has allocated about 200 million dollars annually to support the construction of biogas plants. The state subsidy for each installation is approximately 50% of the average cost. Thus, the government has achieved an annual increase in the number of biogas plants to 1 million per year.

In Europe, there are more than 500 bio-stations for receiving gas from landfills, but they provide for only 40% of biogas production in general. The main obstacle of biogas usage as an alternative fuel for transport vehicles is the high cost of its refinement. This makes its small-scale production economically unprofitable. Sweden is one of the most advanced countries in the use of biogas as automotive fuel. In Gothenburg, more than 4,000 cars are functioning on biogas.

Components of biogas

Biogas more than by half (about 50-65%) consists of methane (CH_4). It also contains carbon dioxide (CO_2), about 25-30%, as well as other gases such as water vapor, hydrogen sulfide, carbon monoxide, nitrogen and others. Depending on the conditions in which biogas is obtained its compound may vary (tab. 1).

TABLE 1. *Components of biogas*

Component	Amount, %
methane	50-60
carbon dioxide	25-30
hydrogen	1.0
hydrogen sulfide	3.0
nitrogen	10.0
oxygen	2.0

Refinement of biogas

In order to use biogas as a fuel for internal combustion engines, it is necessary to pre-clean biogas from moisture, hydrogen sulfide and carbon dioxide. Cleaning biogas from moisture lays in reducing its temperature. This is achieved by passing biogas through a cooled tube to condense the moisture at lower temperatures. When the gas is reheated, the moisture content in it is significantly reduced. Such drying of biogas is especially useful for used dry gas meters, since they are necessarily filled with moisture over time. Hydrogen sulfide, mixed in biogas with water, forms an acid that causes corrosion of the metal. This is a serious limitation of the use of biogas in engines. The most simple and economical way to clean biogas from hydrogen sulfide is dry cleaning in special filters. The metal "sponge" is used as an adsorbent; it consists of a mixture of iron oxide and wood shavings.

The impact of exhaust gases on the environment

The working fluid from the ICE is a product of oxidation and incomplete combustion of hydrocarbon fuel. The waste gases contain a certain amount of toxic and harmful components. Emissions of waste gases – the main reason for exceeding the maximum permissible concentrations of toxic substances and carcinogens in the atmosphere of large cities, the formation of smog, which is a frequent cause of poisoning in the closed space.

The composition and volumes of waste gases emissions determine the amount of pollutants emitted into the atmosphere with them.

When working on a biogas engine with the coefficient of excess air $\alpha < 1$ form the following main combustion products: carbon dioxide (CO_2), carbon monoxide (CO), water vapor (H_2O), hydrogen (H2), nitrogen compounds (N_xO_y), and sulfur dioxide.

Carbon dioxide (CO_2), non-lethal gas, colorless and odorless, and is a natural component of the atmosphere. It has greenhouse properties, that is, it promotes heat retention on the Earth's surface and makes a major contribution to global warming.

Carbon monoxide (CO) is a toxic substance. When it enters the lungs and blood, "binds" the blood cells, which leads to oxygen starvation of the tissues of the body and to death. The share of toxicity of aldehydes is relatively small and is 4-5% of the total toxicity of waste gases. The toxicity of various hydrocarbons varies greatly, but the feature is that unsaturated hydrocarbons in the presence of nitrogen dioxide are photochemically oxidized by exposure to sunlight, forming poisonous oxygencontaining compounds – the components of the smog. The quality of toxic carbon monoxide burning on modern catalytic converters is such that the CO content after the neutralizer is usually reduced to less than 0.1%.

However, the most dangerous ones are nitrogen oxides, which are about 10 times more dangerous than carbon monoxide. Getting to the mucous membranes and into the blood, nitrogen oxides form nitrogen and nitrous acids and other compounds that are hazardous to health and life. Nitrogen oxides are formed in the engine under the high temperature. The higher the temperature in the combustion chambers, the more nitrogen oxides are formed. The return of the exhaust gases to the inlet manifold allows lowering the combustion temperature of the fuel-air mixture, and thus reducing the formation of nitrogen oxides. In this case, the ratio of components in the fuel-air mixture remains unchanged, and the characteristics of the engine power vary slightly.

Sulfur, which is one of the components of the fuels, also reacts with oxygen and hydrogen and can form toxic sulfur dioxide and hydrogen sulfide gases. Carbon dioxide, although it is not toxic for living organisms, increases concentration while increasing the expansion of building materials (limestone, concrete, etc.), accelerates the "aging" of stone buildings and causes corrosion of metals. Thus, the exhaust gases of engines in addition to direct negative effects on the human body bring material damage.

The volatility of biogas from disposal sites leads to a change in the amount of combustion heat and the volume of components of combustion products. This leads to a change in the combustion rate due to changes in the speed of diffusion and the rate of oxidation of intermediate products. Therefore, when working on biogas the obligatory correction of fuel supply and the angle of advance of ignition is necessary. In order to optimize the combustion process, it should be 30-40°C.

Calculation of individual components in combustion products when working with ICEs on biogas from waste products

Proceeding from the elemental composition of fuel, determine the theoretically necessary amount of air for the complete combustion of 1 m^3 of gaseous fuel

$$L_0' = \frac{1}{0.208}\sum\left(n+\frac{m}{4}-\frac{r}{2}\right)\cdot C_nH_mO_r \quad \left(\frac{\text{m}^3\ \text{air}}{\text{m}^3\ \text{fuel}}\right)\left(\frac{\text{kmol of air}}{\text{kmol of fuel}}\right) \tag{1}$$

where C_n, H_m i O_r are carbon, hydrogen and oxygen contents per unit of fuel (1 m^3 or 1 kmol).

The value of the fresh charge that entered the inner cavity of the engine cylinder is determined in this way. For gas fuels in the shown way below:

$$M_1' = \alpha L_0' \quad \left(\frac{\text{m}^3\ \text{fule mixtures}}{\text{m}^3\ \text{fuel}}\right) \tag{2}$$

where α is coefficient of excess air.

The quantitative content of individual components in the combustion products depends on the composition of the combustible mixture, since at $\alpha > 1$ there is complete combustion, and at $\alpha < 1$ – incomplete combustion.

When combustion of the mixture at $\alpha > 1$ carbon and fuel hydrogen are completely oxidized. Quantitative composition of combustion products for gas fuels

$$M_2' = \sum_{1}^{i=4} M_i' = M_{CO_2}' + M_{H_2O}' + M_{O_2}' + M_{N_2}' \quad \left(\frac{\text{m}^3\ \text{comb. prod.}}{\text{m}^3\ \text{fuel}}\right) \tag{3}$$

where:

M'_{CO_2} – the amount of carbon dioxide in the combustion products;

M'_{H_2O} – quantity of water vapor in products of combustion;

M'_{O_2} – the amount of oxygen in the products of combustion;

M'_{N_2} – the amount of nitrogen in the products of combustion.

Number of individual components of combustion products, $\left(\frac{\text{m}^3 \text{ component}}{\text{m}^3 \text{ fuel}}\right)$

$$M'_{CO_2} = \sum n(C_n H_m O_r) \tag{4}$$

$$M'_{H_2O} = \sum \frac{m}{2}(C_n H_m O_r) \tag{5}$$

$$M'_{O_2} = 0{,}208(\alpha - 1)L'_0 \tag{6}$$

$$M'_{N_2} = 0.792\alpha L'_0 + N_2 \tag{7}$$

Values of C, H and O are taken from combustion for one m^3 of fuel. The sum of the accepted values of C, H and O should be equal to one, that is $(C + H + O) \cdot 10^{-2} = 1$.

For the case of $\alpha < 1$ $\left(\frac{\text{m}^3 \text{ comb. prod.}}{\text{m}^3 \text{ fuel}}\right)$

$$M'_2 = \sum_{1}^{i=5} M'_i = M'_{CO_2} + M'_{CO} + M'_{H_2O} + M'_{H_2} + M'_{N_2} \tag{8}$$

The number of individual components of combustion products:

$$M'_{CO_2} = \sum n(C_n H_m O_r) - 0.42\frac{1-\alpha}{1+K}L'_0 \tag{9}$$

$$M'_{CO} = 0.42\frac{1-\alpha}{1+K}L'_0 \tag{10}$$

$$M'_{H_2O} = \sum \frac{m}{2}(C_n H_m O_r) - 0.42\frac{1-\alpha}{1+K}L'_0 \tag{11}$$

$$M'_{H_2} = 0.42K\frac{1-\alpha}{1+K}L'_0 \tag{12}$$

$$M'_{N_2} = 0.79\alpha L'_0 \tag{13}$$

The ratio of the amount of free H_2 and CO in the waste gases is characterized by the K coefficient, which value for biogas

$$K = \frac{H_2}{CO} = 0.45...0.50 \tag{14}$$

The results of calculating the amount of combustion products when using biogas from the landfill are shown in the form of graphs in figures 1-10 at various values of the excess air ratio α and different values of methane content in biogas.

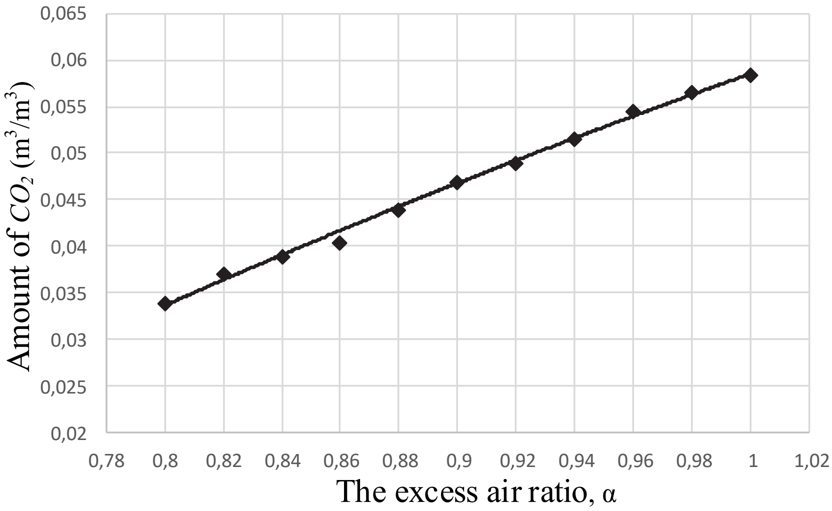

***FIGURE 1**. Dependence of the amount of CO_2 in waste gases on the excess air ratio*

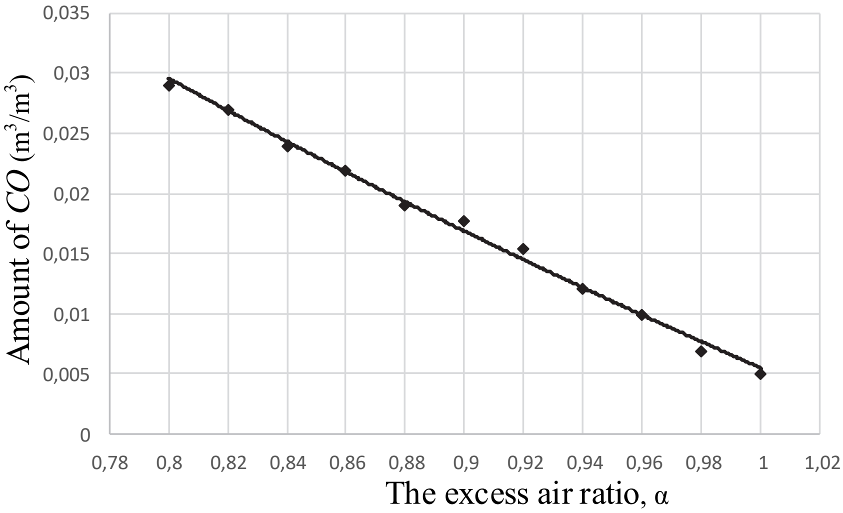

***FIGURE 2**. Dependence of the amount of CO in waste gases on the excess air ratio*

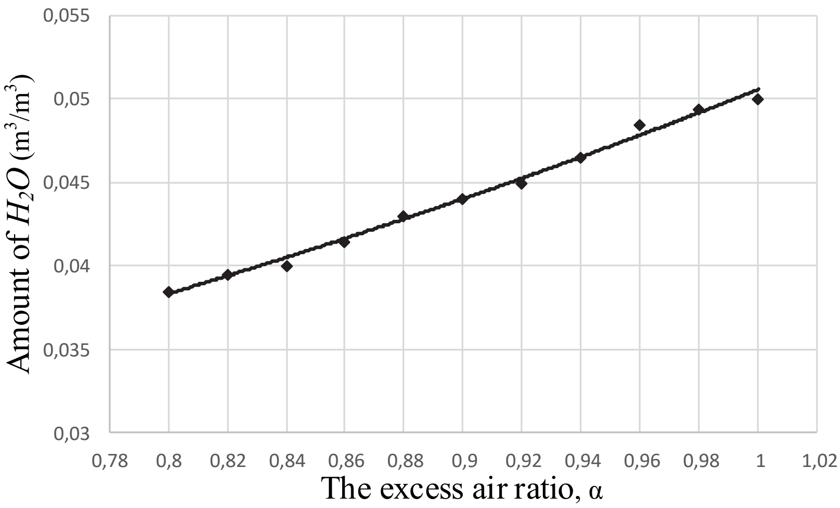

***FIGURE 3**. Dependence of the amount of H_2O in waste gases on the excess air ratio*

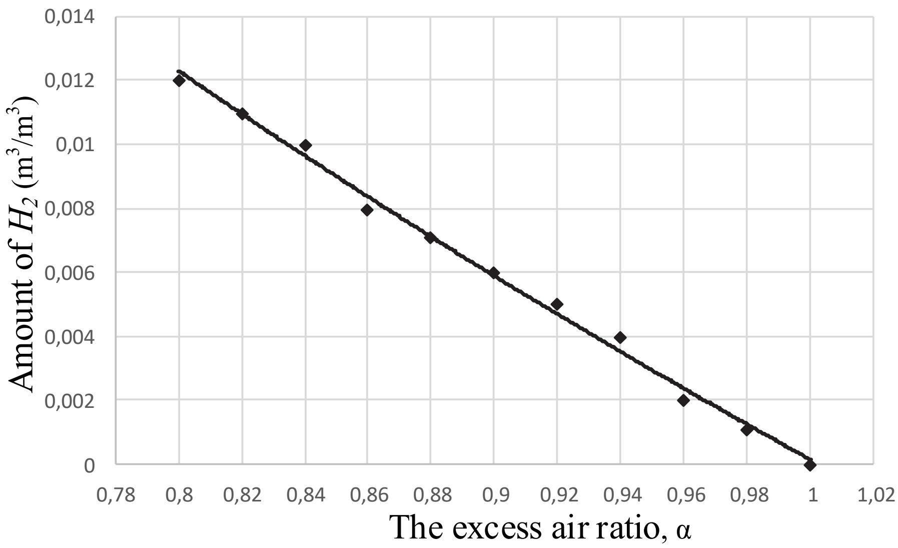

***FIGURE 4**. Dependence of the amount of H_2 in waste gases on the excess air ratio*

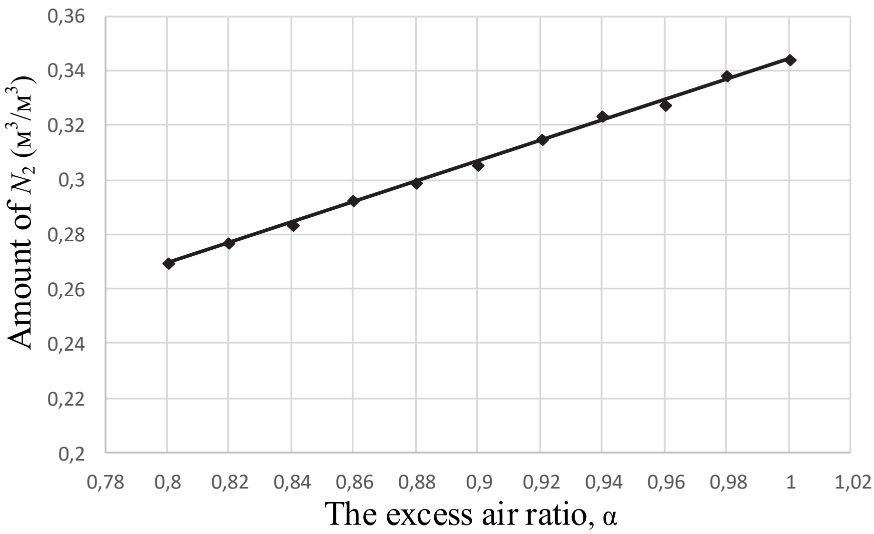

***FIGURE 5.** Dependence of the amount of N_2 in the exhaust gases on the excess air ratio*

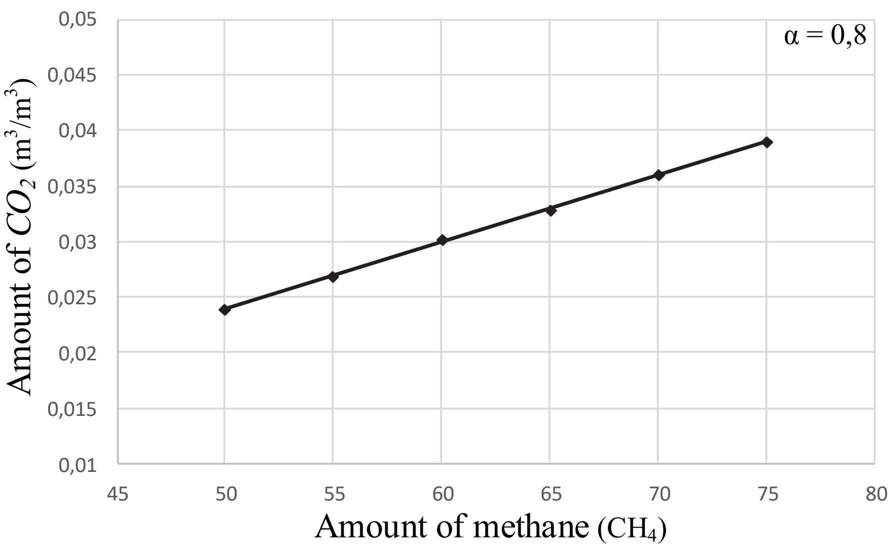

***FIGURE 6**. Dependence of the amount of CO_2 in waste gases on the amount of methane in biogas*

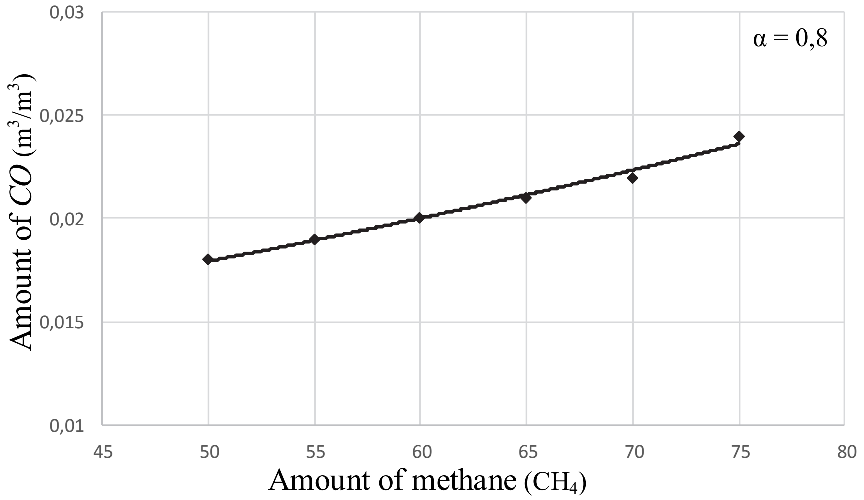

***FIGURE 7**. Dependence of the amount of CO in exhaust gases on the amount of methane in biogas*

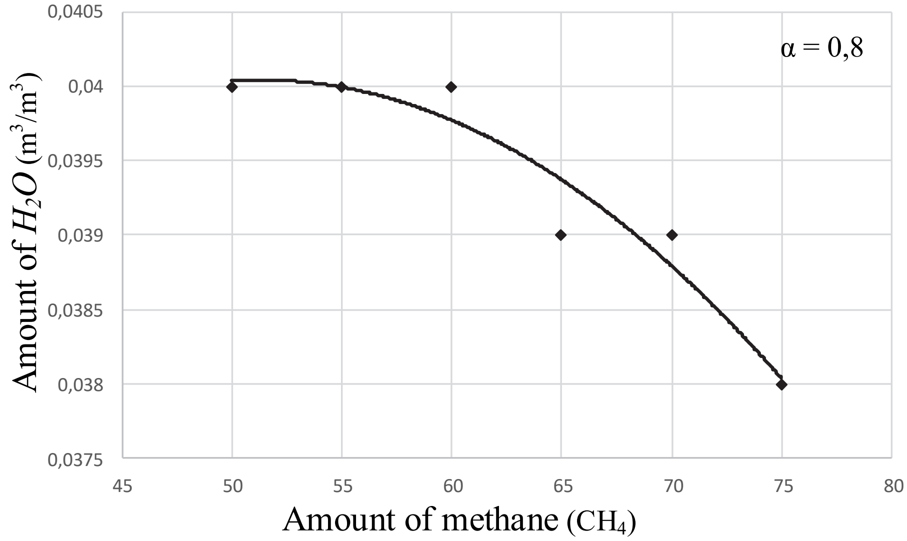

***FIGURE 8**. Dependence of the amount of H_2O in waste gases on the amount of methane in biogas*

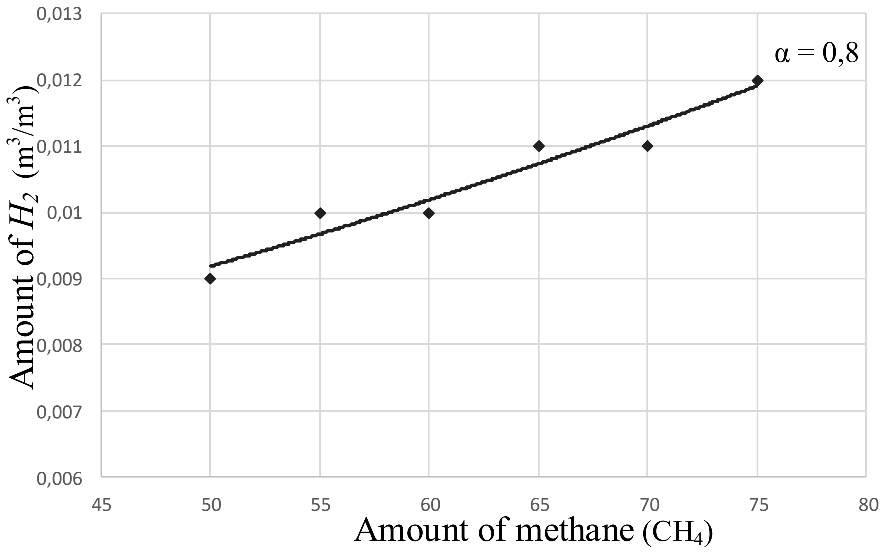

***FIGURE 9**. Dependence of the amount of H_2 in waste gases on the amount of methane in biogas*

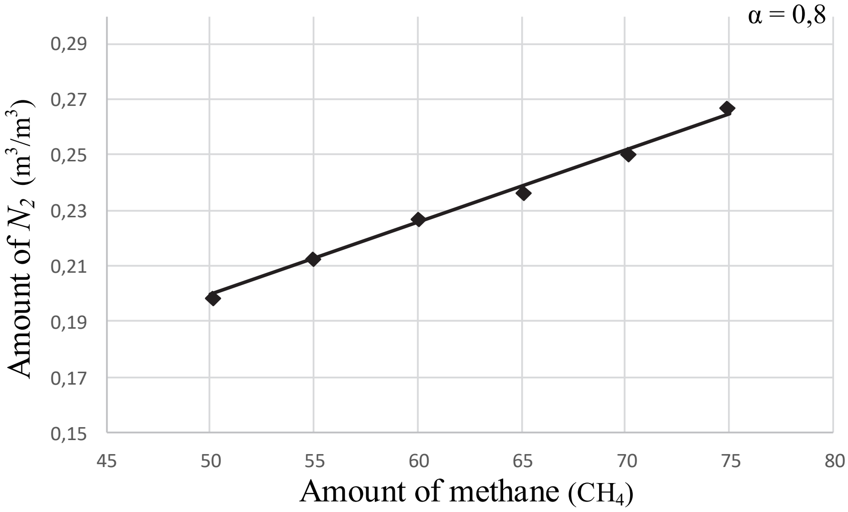

***FIGURE 10**. Dependence of the amount of N_2 in waste gases on the amount of methane in biogas*

The burning rate of biogas is less than natural gas. This is due to the fact that in biogas the amount of methane is smaller.

Conclusions

1. Biogas produced from waste dumps has a number of advantages over natural gas and fuel of petroleum origin and can serve as one of the alternative sources of energy, including fuel for automotive internal combustion engines. This is also proved by a foreign experience.
2. Taking into account the features and instability of biogas from landfills, the working process of internal combustion engines has certain features.
3. The lower heat of combustion and the change in the amount of combustion products leads to a change in the diffusion rate and the rate of oxidation of intermediate products, which requires correction of fuel supply.
4. The use of biogas from landfills gives a significant ecological effect, as the mono and carbon dioxide, nitrogen oxides, sulfur compounds will be less emitted into the environment.
5. Analytical calculations show that the composition of combustion products when using biogas from landfills depends on the coefficient of excess air and methane content in biogas. Thus, with an increase of α from 0.8 to 1.0, the amount of CO decreases from 0.03 kmol/m^3 to 0.01, and the amount of CO_2 increases from 0.03 to 0.06. With an increase in the amount of methane in biogas from 0.5 to 0.75 parts, the amount of CO_2 and CO increases by 5-8%.
6. To optimize the working process of internal combustion engines using biogas from landfills, engines must operate at an excess air ratio of 1.1-1.3.

The economic feasibility of using biogas from landfills as automotive fuel can be estimated by comparing the technical and operational indicators and the economic efficiency of the use of biogas, which will be the subject of further research.

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