Improving the efficiency of biogas utilisation as motor fuel

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Abstract. The use of biogas in the internal combustion engine (ICE) requires the purification of harmful impurities that reduce the quality of operation of the ICE fuel system. A filter device for biogas purification is presented. The zeolite from the Khonguruu deposit of Suntar ulus of the Republic of Sakha (Yakutia) has been tested as a filter to separate impurities. The results of a multifactor experiment on the main factors of the biogas purification process are given: the size of the fractions, the filtering material, its mass, the ratio of the bulk material height to the filter diameter. The best results on biogas purification were obtained at the ratios of the height and diameter H/d=3.0:4.2. The optimum weighted average diameter of granules of the bulk filter material (zeolite) was selected – 0.004 m. and mass of filter media – 0.75-0.8 kg. At these values, the maximum level of biogas purification is observed, where the methane content is 93.3%.

1 Introduction

At the moment, at the enterprises of agro-industrial complex, regardless of the form of ownership, the application of modern biogas technologies is not only profitable, but also the only possible way to meet their energy needs, especially in remote areas and to solve environmental problems associated with waste disposal

Obtaining biogas is one of the ways to ensure the sustainable development of agricultural production, as it produces such resources as: a complete fertiliser, fuel for household needs and agricultural machinery, which can be extracted in the places where agricultural waste is generated.

It is known that many factors influence the composition and quality of the biogas produced: location of the livestock complex, type of feed, ambient temperature, maturation time of digested manure, temperature regime of digestion (mesophilic, thermophilic, psychrophilic), water content in the manure, periodicity of stirring the mash in the digester.

Under conditions of waste digestion in psychrophilic mode, biogas is produced, which contains more than 60% of methane and other gases. Impurities (hydrogen sulphide, nitrogen

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and carbon oxides) negatively affect the operation of the fuel system of the machines. When combusted with water vapour, these impurities form acidic formations, which contribute to a decrease in the performance of the ICE fuel system mechanisms. Thus, when using biogas, it is necessary to purify it from these impurities.

Positive results of the action of filters from milled natural zeolites in diesel engines were obtained in the studies [1-2], conducted at the Altai State Technical University named after I.I. Polzunov. The zeolites have a crystalline structure consisting of aluminosilicon acidic framework, which contains voids and channels where cations of alkaline-earth metals and water molecules are placed. After removal of water during the dehydration process, the zeolite is a microporous

crystalline "sponge" with a pore content of up to 50 per cent of the framework volume. It is this

characteristic determines the relevance and necessity of zeolites application in various branches of production [3-6].

There are deposits of these natural materials in Yakutia, which can be used as filters for biogas purification.

2 Materials and methods

Khonguruu zeolite, of which there are significant reserves in Suntarsky ulus of Yakutia, was used to manufacture the filter.

Table 1 shows the chemical composition of zeolite raw materials, [7-8].

Table 1. Chemical composition of zeolite raw materials, Honguruu deposit, %

SiO2	Al2O3	Fe2O3	CaO	MgO	K2O+ Na2O	TiO2	H2O	impurities
64.11	12.16	1.08	2.62	1.88	3.30	0.13	8.89	4.26

According to its chemical composition, biogas resembles natural gas and can be used in automotive internal combustion engines. According to Swedish and Swiss scientists, biogas can be used in ICE, as by its environmental characteristics biogas is 75% cleaner than diesel fuel and 50% cleaner than petrol. The toxicity of biogas to humans is 60% lower than traditional fuels. In biogas the ratio of methane (CH_4) and carbon dioxide (CO_2) depends on the initial substrate and the characteristic of the fermentation process in the digester. The diagram (Fig. 1) shows the chemical composition of the biogas.

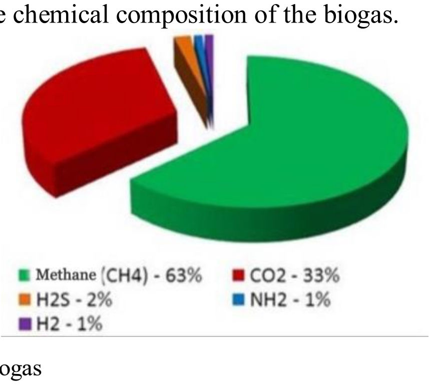

Fig. 1. Impurity content in biogas

The zeolite filter traps molecules CO_2, having a size comparable to the size of micropores of zeolite, for example, in zeolite "Khongurin" micropores have a size of 0.4 nm, and the size of molecule CO_2 is 0.31 nm (see Table 2). Dimensions of the molecule CH_4 are less than

0.2 nm, so they will pass freely through the zeolite filter, which is what is required. That is, the filter output will be purified methane [10].

Table 2. Comparison of the sizes of gas molecules and zeolite pores

Dimensions	Pore sizes zeolite pores	molecular sizes, nm				
		H_2S	CO_2	H_2O	CO	NH_3
Unit of concentration in parts per million (ppm)	300-500	7.2	0.31	29	17.5	28.2
Molecule/pore sizes	0.3-0.5	10.2	0.57	0.276	20.38	19.96

As we can see from the data of Table 2 zeolite of Khongurinskoye deposit can be used as a filtering material for biogas purification.

Filters in the fuel system should be compact and have a collapsible design for replacement of the filter element. A housing from the coarse fuel filter of the KamAZ-740 vehicle was used. This filter was modernised (Figure 3): inlet and outlet connections were installed; an adapter was made to fix the housing cover and gas pipe; a partition to the gas pipe was installed. The design of the filter with zeolite filler is shown in Figure 2.

Principle of operation: biogas flows into the filter housing 2 through the gas inlet connection 10, passing through the central channel 9 and moving upwards (methane is lighter than air), through the lower partition 1 of the filter element, gets into the layer of zeolite granules. Here there is purification from harmful impurities of biogas: hydrogen sulphide, carbon dioxide, which settle in the pores of zeolite. The purified biomethane passed the upper partition and exited through the outlet connection 7. The filtering material (zeolite) can be regenerated by heating to 200 0C.

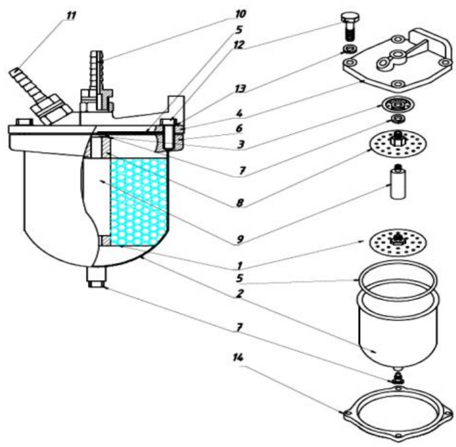

Fig. 2. Biogas purification filter: 1 – lower filter element baffle; 2 – filter housing; 3 – distributor; 4 – filter cover; 5 – O-ring; 6 – cup flange; 7 – spring washer 14; 8 – upper filter element baffle with adapter; 9 – centre channel; 10 – biogas inlet connection; 11 – biogas outlet connection; 12 - bolt; 13 – spring washer; 14 – cup flange.

To determine the design parameters, filters of different sizes were used: height - 0.5; 0.4; 0.3; 0.2; 0.15 m and diameter - 0.06; 0.08; 0.10; 0.12; 0.14 m accordingly to the number of experiments in the conducted experiment. All filters were filled with zeolite of 0.004 m fraction and biogas with different methane content was passed to determine the degree of purification. Before and after filter cleaning, in each experiment, the biogas composition was measured for the content of CH4 gas analyser AMT-3. At the end of each experiment the adsorbents were measured by weighing on laboratory scales of model ACOMJW-1.

To determine the dependence of adsorption properties of zeolite on the size of fractions, zeolite was poured into the filter, measuring its bulk volume.

The study design was based on the multifactorial experiment technique [11]. Figure 3 shows the a priori ranking diagram in the study of the filtration process. According to the results of a priori ranking, the most influential factors were determined: the size of zeolite granules; the mass of zeolite in the filter; the ratio of filter height to diameter.

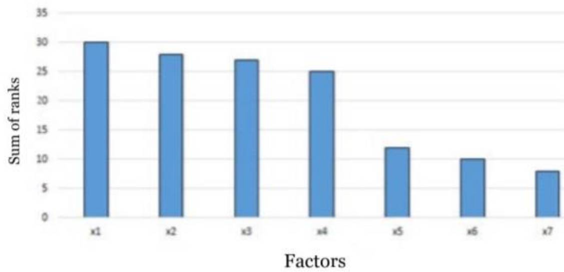

Fig. 3. Average a priori ranking diagram for the study of the filtering process: x1- weighted average size of zeolite granules, mm; x2 – zeolite mass in the filter, g; x3 – filter height to diameter ratio; x4 – methane concentration in biogas, %; x5 – biogas moisture, %; x6 – biogas supply pressure, MPa; x7 – biogas temperature, K.

Table 3 summarises the factors and their area of study and Table 4 summarises the plan matrix and their levels of variation.

Table 3. Factors and their area of study

Factor	Designation	Real value level values			Code	Level of coded value of the factor		
		lower	basic	high		lower	basic	high
Weighted average size of zeolite granules, mm	d	2	4	6	x_1	-1	0	+1
Weight of zeolite in the filter, g	m	500	750	1000	x_2	-1	0	+1
Filter height to diameter ratio	H/d	2.5	3.25	4	x_3	-1	0	+1

Table 4. Matrix of plan and level of variation of factors

Designation	Factor			Y% methane from biogas
	Weighted average sizes of zeolite granules, mm	Weight zeolite in filter, g	Ratio filter height to diameter	
1	1	1	0	70
2	-1	-1	0	80
3	1	-1	0	75
4	-1	1	0	82
5	1	0	1	76
6	-1	0	-1	85
7	1	0	-1	72
8	-1	0	1	87

9	0	1	1	92
10	0	-1	-1	78
11	0	1	-1	90
12	0	-1	1	84
13	0	0	0	95
14	0	0	-1	90
15	0	0	1	84

The degree of gas purification efficiency is determined by the formula (1)[12]:

$$E = \frac{Cp - Cd}{Cp} * 100\% \tag{1}$$

where – *E* degree of gas purification, %; *CD* – methane content in biogas before purification; *CP* – methane content in biogas after purification.

3 Results and discussion

The results of biogas purification efficiency tests are summarised in Table 5, from which we can see that the filter with weighted average diameters of zeolite particle granules 0.004 m gives the maximum percentage of purification. Figure 4 shows experimental data and theoretical curve obtained by polynomial approximation.

Table 5. Biogas purification efficiency depending on the size of zeolite fractions

No. of experience	Particle diameter d, m			
	0.002	0.003	0.004	0.005
	Cleaning efficiency, ***E*** %			
1	56	73	92	80
2	62	75	95	76
3	66	83	92	75
4	63	88	90	81
5	62	83	86	78
mean value of experiments	62	80	91	78

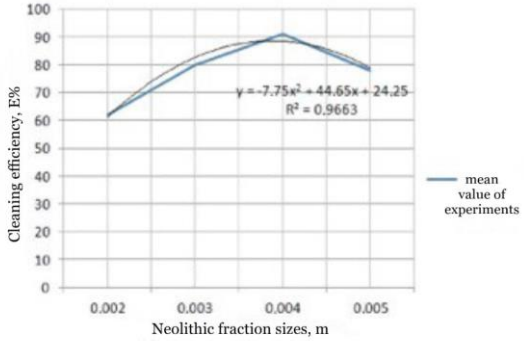

Fig. 4. Dependence of biogas purification efficiency on the size of zeolite fractions

Dependence of biogas purification efficiency on the ratio of geometric dimensions of the filter (H - height) and (d-diameter) is shown in Table 6. Figure 5 gives a graphical interpretation.

Table 6. Results of biogas purification efficiency depending on design parameters of the filter

Experience number	1	2	3	4	5
	Hl/dl	Hl/d2	Hl/d3	Hl/d4	Hl/d5
H/d	2.5	1.9	1.5	1.3	1.1
E, %	42	38	35	45	40
	H2/dl	H2/d2	H2/d3	H2/d4	H2/d5
H/d	3.3	2.5	2.0	1.7	1.4
E, %	82	55	37	32	30
	H3/dl	H3/d2	H3/d3	H3/d4	H3/d5
H/d	5.0	3.8	3.0	2.5	2.1
E, %	32	82	85	76	66
	H4/dl	H4/d2	H4/d3	H4/d4	H4/d5
H/d	6.7	5.0	4.0	3.3	2.9
E, %	50	56	90	92	88
	H5/dl	H5/d2	H5/d3	H5/d4	H5/d5
H/d	8.3	6.3	5.0	4.2	3.6
E, %	50	53	60	78	86

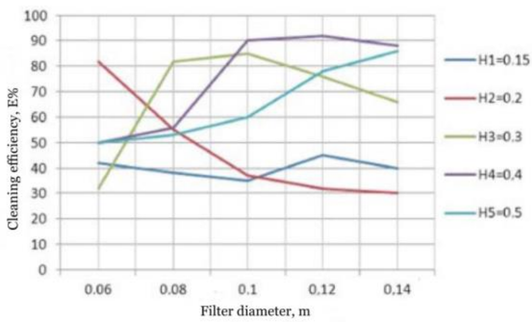

Fig. 5. Dependence of biogas purification efficiency on filter H/d ratio

Thus, the conducted experimental studies have shown that the maximum efficiency of biogas purification was obtained at the ratios of the height and diameter of the filter housing **H/d=3.0:4.2**.

4 Conclusion

The composition of biogas allows its use in all processes in which natural gas is used. Compared to other petroleum fuels, biogas produces the least amount of carbon dioxide and particulate matter emissions during ICE operation. The gas-fuelled engine runs quieter and vibrates less than an oil-fuelled engine, which contributes to better working conditions and environmental safety, reducing the risk of fire and explosion hazards [13-16].

Biogas production is especially promising in remote areas engaged in agricultural production. Biogas will be an additional resource as an alternative fuel for refuelling tractor vehicles, for combustion in space heating boilers, gas burners for water heating. Biogas purification will improve its performance. As the conducted researches have shown, natural zeolite of "Khongurit" mark can be successfully used as a filtering material. The results of the research proved the good filtering capacity of this raw material for the purification of biogas from unnecessary impurities, which contributes to an increase in methane concentration. The best results were achieved in the filter height and diameter H/d=3.0:4.2, at that the optimal weighted average diameter of the granules of the bulk filter material (zeolite) is 0.004 m, the mass of the filtering raw material should be 0.75-0.8 kg. At these parameters of the filter, the maximum degree of biogas purification is observed. At the filter outlet biogas with methane content of 93.3% was obtained.

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