Experimental studies on the adaptation of micronizer infrared burners for biomethane

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Abstract. To destroy pathogenic microflora, increase digestibility and nutritional value, cereals, which are part of compound feeds, are subjected to IR processing in a micronizer. However, in order to transfer micronizer burners from natural gas to biogas generated during anaerobic methane digestion of livestock complex waste, it was necessary not only to purify biogas from carbon dioxide, hydrogen sulfide and other associated gases, i.e. to obtain biomethane, but also to improve the design of the module heating burners with radiating nozzles. The efficiency of the GIK-8 infrared radiation burner on purified biogas with a CO\textsubscript{2} content of 0.2-34.0\% was experimentally established, and an improved burner design for a micronizer with adaptation to its operation on biomethane was developed. The geometric dimensions and shape of the micronizer infrared burners with the adaptation of their operation on biomethane are specified. The efficiency of the GIK-8 infrared radiation burner on purified biogas with a CO\textsubscript{2} content of 0.2-34.0\% was established. The temperature of the heating surface of the GIK-8 burner in gas mixtures with a CO\textsubscript{2} content of 18-34\% is 900-950 °C, which does not differ from the nominal temperature when operating on natural gas. The possibility of ignition of the GIK-8 cold burner at 33\% CO\textsubscript{2} content in purified biogas was determined.

1. Introduction

One of the promising ways to increase the feed value of grain fodder is micronization, the positive effect of which is manifested in an increase in the digestibility of starch, a change in the protein complex of the grain, inactivation of inhibitors of the digestive tract, the destruction of pathogenic microflora (the level of fungal flora decreases by 99.5\%, the bacterial flora by 99.9\%), the formation of aromatic substances that improve the taste of grain and, ultimately, increase the productivity of animals.

The micronization of grain is especially important when growing calves during milk feeding and piglets of early weaning, the digestive tract of which at this age is poorly adapted for digestion and assimilation of nutrients of plant foods.

During the micronization, native grain starch is converted to the modified one. The content of sugars and dextrins increases 2-3 times, the degree of gelatinization reaches minimum 35\%. The availability of starch for the animal organism due to its hydrolysis increases 2-5 times. The average daily weight gain of piglets fed mixed feed with barley processed by micronization
(infrared processing) with subsequent flaking (flattening) was higher by 12.5-34.1%, and the feed consumption was lower by 4.5-12.2% than with a control diet.

However, in order to transfer micronizer burners from natural gas to biogas generated during anaerobic methane digestion of livestock complex wastes, it was necessary not only to purify biogas from carbon dioxide, hydrogen sulfide and other associated gases, i.e. to obtain biomethane, but also to improve module heating burner with radiating nozzles.

In this regard, to increase the efficiency of the micronizer, it is necessary to modernize the modules of infrared burners that determine the intensity of the IR processing of grain crops in the micronizer.

2. Materials and methods

To conduct experimental studies, a test procedure was developed for the GIK-8 module-heating burner with a consideration of the general requirements defined by standards and specifications.

When testing gas burners with radiating nozzles, the following characteristics were determined: the average temperature of the radiating surface; uniform distribution of temperature over the radiating surface; temperature of enclosing surfaces and manual controls; nature of ignition and extinction; initial ignition time; reignition time; the transition period from the Big Flame mode to the Small Flame mode; closing time of the automatic shut-off valve; resistance to wind.

When testing burners and their automation equipment in the range of working gas pressures, the following is verified: the possibility of remote ignition while opening an automatic locking device; combustion control, and in case of extinction, restoration of combustion; closing the automatic locking device when it is impossible to restore combustion; backflash into the mixer; power outage; turning off the gas supply.

In the range of operating regulation, the dependence of the airflow coefficient on the gas pressure before the burner is verified. The airflow rate is determined either by the composition of the gases in the sample of the air mixture, or by the composition of undiluted combustion products taken directly before the radiating surface.

An analysis of the combustion products before the radiating plate determines the concentration of carbon monoxide, nitrogen oxides and heat loss from chemical incompleteness of combustion. Consumption characteristics of the burner and the hydraulic resistance coefficients were determined by purging the gas path [1-3].

The coefficients of hydraulic resistance of the gas path \( \xi_g \) and air path \( \xi_a \), respectively, were determined by the formulas:

\[
\xi_g = \frac{2P_{a,b} 10^3}{\rho_{a,b} W_{a,b}^2}, \\
\xi_a = \frac{2P_a 10^3}{\rho_a W_a^2},
\]

where \( P_{a,b} \) – excess pressure of air simulating gas at the inlet to the burner, kPa; \( P_a \) – excess air pressure before the burner, kPa; \( W_{a,b} \) and \( W_a \) – average consumption speed in characteristic sections of the gas and air paths, m/s. For injection burners and two-wire burners \( P_{a,b} < 90 \) kPa:

\[
\rho_{a,b} = 1.29 \left( \frac{273}{T_a} \right) \left[ \frac{(P_{a,b} + B_o)}{101,3} \right]^{\frac{1}{k}} \left[ \frac{B_o}{(P_{a,b} + B_o)} \right]^{\frac{1}{k}},
\]

where \( k \) is the adiabatic exponent for air.

Based on the results of cold tests, the dependences of the gas flow and air flow on their pressures before the burner and the dependences of the hydraulic resistance coefficients on the gas path and air path on the Reynolds numbers for gas flow and airflow in characteristic sections were drawn. The fluctuations in the value of the Wobbe number, which is the ratio of the highest calorific value of the gas, MJ / m³, per square root of its density relative to air, should not exceed \( \pm 5\% \) of the average value
during the burner test. The higher the Wobbe number of the gas, the higher the calorific value of the 
gas. Pure methane has a Wobbe number of 50.7; natural gas – 50.1-50.3, biomethane – 48.6-49.2.

To determine the possibility of using biogas as a fuel for the GIK-8 burner, experiments were 
carried out on gas mixtures with different ratios of methane and carbon dioxide.

During each experiment, the following features were monitored and determined: steady burner 
ignition and combustion control in a stationary mode using special automation with ignition and flame 
control electrodes; determination of the temperature of the burner body in a horizontal position; 
compliance of the parameters of the combustion products with the declared indicators. The 
experiments for the study of the GIK-8 burner were carried out in accordance with the scheme shown 
in Figure 1.

The purpose of the experiments was to determine the permissible carbon dioxide content in purified 
biogas when feeding it to a gas infrared heating system with GIK-8 burners. The initial biogas had the 
following parameters: CH\textsubscript{4} – 0-60%; CO\textsubscript{2} – 35-45%; H\textsubscript{2}S – 0-150 ppm; O\textsubscript{2} – 1%; N ~ 1%; H ~ 1%.

Tasks of the experimental study are: testing the GIK-8 burner on a mixture of gases with different 
volume ratios of methane and carbon dioxide, common for biogas; determination of burner 
specifications for various volumetric ratios of methane and carbon dioxide [7, 8].

Figure 1. Test plan for the GIK-8 burner on model biogas

The GIK-8 infrared burner presented for testing was manufactured by KZGO LLC (Kamensk-
Shakhtinsk, Rostov Region) and passed certification tests.

The basis of the infrared heating system was 40 GIK-8 special-purpose infrared burners designed 
for infrared heating during the combustion of biomethane. In this case, the burners provided a uniform 
combustion mode of the gas mixture, eliminating overheating of the local areas of the ceramic nozzle.

The test facility for the GIK-8 burner was a device that provides: installation of a burner; placing 
the burner at an accessible height that allows servicing the elements of the burner, despite the fact that 
the heating surface is horizontal and directed downward; mixing and supplying in the required 
quantities both air and gases involved in the test variants; removal of combustion products under an 
exhaust hood; measurement of all parameters of the burner operation for each test option, including: 
air and biogas flow rates, temperature of the radiating surface, combustion products, burner body 
elements, biogas and air pressure, response times of the ignition automatics and flame control, 
composition of the combustion products and gas mixture, noise characteristics.
The experimental procedure:
1. The experiments were carried out for each of the composition variants of the model gas.
2. The first series of experiments (for each composition variant of the model gas) was carried out without igniting the burner. The task of the experiments is to determine the position of controlling elements, the pressure of gases and air before the mixer, the time required to obtain a gas-air mixture with \( \sigma = 1.0-1.1 \). Rigging was carried out by changing the settings of the pressure regulators.
3. The second stage of the tests was carried out with the ignition of the burner. Ignition was conducted by the ignition pin. After combustion stabilization, all required parameters were measured.
4. If it is impossible for the burner to reach a stable combustion mode according to a particular model gas supply, the onset of stable combustion, all parameters were measured.

Measuring instruments and controllers of the test facility for an infrared burner using model gas variants provided the supply and measurement of gas and air volumes, measurement of the composition of the combustion products and air-gas mixture, measurement of the temperature of the combustion products, the body and the radiating surface of the burner within the limits indicated in table 1.

### Table 1. Limit values of the parameters of the test facility

| Parameter                              | Unit | Value          |
|----------------------------------------|------|----------------|
| Model gas flow rate and composition    | -    | -              |
| Air flow rate                          | l/h  | -              |
| Gas pressure before mixer              | kPa  | 3.5            |
| Air pressure before mixer              | kPa  | 3.5            |
| Atmospheric pressure                   | kPa  | 100,0          |
| Excess air factor                      | -    | 1.02-1.08      |
| Temperature:                           |      |                |
| - radiating surface                    | °C   | 900-1100       |
| - combustion products                  | °C   | less than 1000 |
| - burner body                          | °C   | maximum 300    |
| - surrounding air                      | °C   | -15-20         |
| The response time of the ignition and  | s    | 0.5-20         |
| flame control automation               |      |                |

3. The results of experimental studies of the GIK-8 burner
In accordance with the research methodology and experimental design, a test facility for the GIK-8 burner was mounted (Figure 2, a).

Studies of the effect of various component composition of biogas on the combustion rate and power loss of a grain micronization installation have been conducted (Table 2).

In the course of experimental studies, it was found that with an increase in the \( \text{CO}_2 \) content to 50%, a nearly two-fold increase in the gas mixture consumption will be required to stabilize the temperature mode of the micronization process. This significantly reduces the performance of one burner for the processed grain [4-6].

The dependence of the combustion rate on the \( \text{CO}_2 \) content at different gas mixture flows is asymptotic and approaches a minimum value of 0.28 m/s, which indicates the need to reduce the \( \text{CO}_2 \) concentration to 10% in order to obtain an optimal combustion rate of 0.4 m/s.

The dependence of the performance of one burner on the total flow rate of the gas mixture at various values of the \( \text{CO}_2 \) content was established, and losses of the burner power on the \( \text{CO}_2 \) content were revealed depending on the specific productivity of the micronizer. Thus, the real possibility of replacing natural gas with biogas for the operation of a gas infrared heating system with micronizer burners is shown [9, 10].
Figure 2. The test facility in operation: a – preparation and analysis of the gas mixture; b - thermal imaging of the burner in stationary mode.

Figure 2b shows the operation of the GIK-8 burner in a preheated state, and the graph (Figure 3) demonstrates the temperature mode of burner operation.

Table 2. Flow rates of biogas of various component composition taking into consideration the combustion rate and possible power loss

| No. | Composition of the model gas,% vol. | Flow rate of gas-are mixture components, l/h | Gas mixture total flow rate, l/h | Optimum combustion rate without flame liftoff, m/s | Burner power loss, % | Possible amount of processed grain, kg |
|-----|-----------------------------------|---------------------------------------------|---------------------------------|-----------------------------------------------|---------------------|--------------------------------------|
|     | CH₄ | CO₂ | Air | Biogas | O₂ | N₂ | CH₄ | CO₂ | 8 | 9 | 10 | 11 |
| 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   |     |     |     |     |     |
| 1   | 100 | 0   | 1800| 7200| 900 | 0   | 9900|     |     |     |     |     |
| 2   | 90  | 10  | 1408| 5632| 704 | 78  | 7822| 0.45 | -   | 2200 |     |
| 3   | 85  | 15  | 1330| 5325| 665 | 117 | 7437| 0.38 | 15  | 1870 |     |
| 4   | 80  | 20  | 1254| 5018| 627 | 156 | 7055| 0.36 | 20  | 1760 |     |
| 5   | 70  | 30  | 1120| 4480| 560 | 240 | 6400| 0.33 | 30  | 1540 |     |
| 6   | 60  | 40  | 1008| 4032| 504 | 336 | 5880| 0.30 | 40  | 1320 |     |
| 7   | 50  | 50  | 898 | 3594| 450 | 450 | 5392| 0.28 | 50  | 1100 |     |

To reduce the cost of biogas purification and its use in the burners operation in a micronizer, it should be brought to the composition of natural gas according to National Standard with the extraction
of CO$_2$, H$_2$S and water from it. In the process of micronization, it is sufficient to maintain a carbon dioxide content of 10-20%, which will ensure the normal burners operation, without any design changes.

Figure 3a shows the change in temperature $T$ of the ceramic working surface when operated on a methane-air mixture in nominal mode 1 (Table 3). The main temperature increase occurred during the first two minutes of burner operation. Small periodic temperature fluctuations ($\pm 3^\circ$C in stationary mode) are caused by characteristic fluctuations in air flow ($\pm 1.7$ l/min, or 1.5% of the set point) as a result of compressor operation. The burner exit process in the steady (nominal) mode began from the moment of ignition. It was determined in experiments that when the CO$_2$ content in the biogas mixture increased from 0.2 to 34%, the ignition process did not visually change.

Figure 3b shows the temperatures when working on a model mixture containing carbon dioxide. The burner was ignited and heated in mode 1, after which CO$_2$ was mixed into the gas mixture with a flow rate corresponding to 18, 28, and 34% of CO$_2$ in the model mixture (modes 2, 3, and 4, respectively). At the same time, the flow rates of natural gas and air were kept constant.

![Figure 3. Changes in the temperature of ceramics ($T_1$) and the body upper wall ($T_2$) during burner operation: a – on a methane-air mixture in a mode with nominal parameters; b – the operation of a heated burner with varying the composition of the model mixture of methane and CO$_2$](image)

**Table 3.** Burner operation parameters in various modes

| Operation mode | Model mixture composition, vol. % | Flow rate, l/min | Excess air factor | Pressure, mbar |
|----------------|----------------------------------|------------------|------------------|---------------|
|                | CH$_4$ | CO$_2$ | Air | Gas | CO$_2$ | Total flow rate | Mode mixture before mixer | Total mixture before burner |
| Ignition with CO$_2$ | 67 | 33 | 135.4 | 13.4 | 6.5 | 155.3 | 1.06 | 25 | 7 |
| 1              | 100 | 0    | 133.7 | 13.4 | 0.0 | 147.1 | 1.05 | 21.0 | 6.0 |
| 2              | 82  | 18   | 135.4 | 13.1 | 2.9 | 151.4 | 1.09 | 24.0 | 6.5 |
| 3              | 72  | 28   | 134.6 | 12.8 | 5.1 | 152.5 | 1.10 | 24.5 | 7.0 |
| 4              | 66  | 34   | 135.4 | 13.1 | 6.9 | 155.4 | 1.09 | 25.5 | 7.0 |
Therein, the analysis using thermal imaging showed (Figure 4) a tendency to a change in the average temperature ($T_3$) of the selected characteristic area of the ceramic surface during the transition to the next mode. The temperature at the junction of ceramic plates ($T_4$), which characterizes not so much the state of the working surface as the heating of the ceramic material, remained virtually unchanged when switching to a new mode [11, 12].

![Figure 4.](image)

**Figure 4.** The temperature field recorded with a thermal imager: a – mode 1 (without CO$_2$); b – mode 2; c – mode 3; d – mode 4. The location of the burner in the images corresponds to Fig. 2b and is mirrored vertically compared to the rest of the figures (Modes a, b, c, and d are shown in Table 3).
In addition to changing the composition of the operating gas mixture, a possible reason for the change in temperature \( T_3 \) was a slight difference in the flow rate of natural gas in different modes and, as a consequence, differences in the current burner power. The burner operating parameters in the indicated modes are given in Table 3.

4. Conclusion

The efficiency of the GIK-8 infrared radiation burner on purified biogas with a CO\(_2\) content of 0.2-34.0% was experimentally established, and an improved burner design for a micronizer with adaptation to its operation on biomethane was developed. The dimensions and shape of the infrared micronizer burners with the adaptation of their operation on biomethane are specified.

It was established that the temperature of the heating surface of the GIK-8 burner on gas mixtures with a CO\(_2\) content of 18-34% is 900-950 °C, which does not differ from the nominal temperature when operating on natural gas.

The possibility of ignition of the GIK-8 cold burner at 33% of CO\(_2\) content in purified biogas was determined.

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