TO THE QUESTION OF BIOGAS COMBUSTION IN VORTEX BURNERS

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Abstract. The introduction of bio gas in the heat-generating power industry is impossible without the development and modernization of the main and auxiliary boiler equipment, as well as burner devices. The possibility of using the GGV-100 vortex gas burner for burning bio gas with a reduced methane content is considered. The main parameters of gas fuel are determined: the required volumes of oxygen and air for complete combustion of bio gas, theoretical and actual volumes of combustion products, the value of the maximum normal flame propagation velocity. In the software package Solid Works Flow Simulation, a computer model of the GGV-100 vortex gas burner was developed, as a result of the calculation, patterns were constructed of the change in the speed of the gas-air mixture in the longitudinally vertical plane of the section of the gas burner-furnace

Natural gas is the most efficient and environmentally friendly source of energy, which is the main fuel for energy supply of a huge number of consumers of various types, including agricultural enterprises. One of the most promising and effective areas in the energy supply of agricultural enterprises is the production and use of a renewable energy source - bio gas. Biogas consists of 30-80% methane, 20-50% carbon dioxide, and a small amount of other gases (hydrogen sulfide, nitrogen, oxygen, hydrogen, ammonia) [1]. Since the methane content in bio gas starts with only 40% of the total gas mixture volume, and the gas burners of most devices are designed for burning natural gas with a methane content of more than 90%, there is a need for research on the development of gas burners for burning bio gas fuel.

The purpose of the work is to determine the main energy parameters of bio gas fuel and study the process of formation of a gas-air mixture in low-pressure vortex burners.

When using bio gas of various compositions in gas burners, it is necessary to supply an amount of air that ensures optimal combustion of the gas-air mixture formed as a result of mixing of the gas used with the supplied air.

Let's calculate the theoretical volume of dry air for combustion of bio gas with the following conditional composition: CH₄ = 45%, CO₂ = 52%, N₂ = 1%, H₂S = 2%.

The consumption of oxygen and air is determined on the basis of the combustion equations of the components that make up the bio gas [2].

\[
\text{Methane: } \text{CH}_4 + 2\text{O}_2 + 7.52\text{N}_2 = \text{CO}_2 + 2\text{H}_2\text{O} + 7.52\text{N}_2; \\
\text{Hydrogen sulfide: } \text{H}_2\text{S} + 1.5\text{O}_2 + 5.64\text{N}_2 = \text{SO}_2 + \text{H}_2\text{O} + 5.64\text{N}_2.
\]

On the basis of the above combustion equations for components of gaseous fuel, the volume of oxygen required for combustion of 1 m³ is determined by the formula:

\[
V_{o_2}^\circ = 0.01 \left[ 0.5\text{CO} + 0.5\text{H}_2 + 2\text{CH}_4 + 1.5\text{H}_2\text{S} + \sum \left( m + \frac{n}{4} \right) \nu_m H_n - O_2 \right]
\]

\[
V_{o_2}^\circ = 0.01 \left[ 2 \cdot 45 + 1.5 \cdot 2 \right] = 0.93m^3
\]

The volume of air \( V_{\text{air}} \), which is necessary for the combustion of gas, is determined from the air content of 21% of oxygen by volume, m³ / m³ of gas.
\[ V'_a = \frac{100}{21} \cdot V'_v = 4.76 \cdot V'_o, \, m^3 \]  
(3) 

\[ V'_o = 4.76 \cdot 0.93 = 4.43 m^3 \]  
(4) 

The theoretical volume of dry trihydric gases, m3/m3:

\[ V_{CO_2}^0 = 0.01 \cdot (CO_2 + CO + \sum mC_nH_n) \]  
(5) 

\[ V_{SO_2} = 0.01 \cdot H_2S \]  
(6) 

\[ V_{CO_2}^0 = 0.01 \cdot (52 + 45) = 0.97 m^3 / m^3 \]  
(7) 

\[ V_{SO_2} = 0.01 \cdot 2 = 0.02 m^3 / m^3 \]  
(8) 

Theoretical yield of nitrogen in combustion products:

\[ V_{N_2}^0 = 0.79 \cdot V'_o + 0.01 \cdot N_2 \]  
(9) 

\[ V_{N_2}^0 = 0.79 \cdot 4.43 + 0.01 \cdot 1 = 3.51 m^3 / m^3 \]  
(10) 

Theoretical yield of water vapor in the combustion of gaseous fuels:

\[ V_{H_2O}^0 = 0.01 \left[ H_2 + H_2S + \sum \frac{n}{2} C_nH_n + 0.124 \cdot d \right] + 0.0161 \cdot V'_o \]  
(11) 

where \( d \) is the absolute humidity of the gaseous fuel, g / m^3 (we take 5 g / m^3 [3]). 

\[ V_{H_2O}^0 = 0.01 \left[ (2 + 2 \cdot 45 + 0.124 \cdot 5) + 0.0161 \cdot 4.43 \right] = 0.99 m^3 / m^3 \]  
(12) 

The theoretical volume of dry gases consists of three-atom gases and nitrogen:

\[ V_{c.c.}^0 = V_{H_2O}^0 + V_{N_2}^0 \]  
(13) 

where

\[ V_{H_2O}^0 = V_{CO_2}^0 + V_{SO_2}^0 = 0.97 + 0.02 = 0.99 m^3 / m^3 \]  
(14) 

\[ V_{c.c.}^0 = 0.99 + 3.51 = 4.5 m^3 / m^3 \]  
(15) 

The total theoretical volume of combustion products is:

\[ V'^o = V_{c.c.}^0 + V_{H_2O}^0 \]  
(16) 

\[ V'^o = 4.5 + 0.99 = 5.49 m^3 / m^3 \]  
(17) 

The actual volumes of combustion products are calculated with considering the indicator of excess air \( \alpha = 1.2 \).

Due to the fact that the process of oxidation of combustible fuel compounds is basically completed in the combustion chamber, the volume of tri-gas \( V_{H_2O} \) remains unchanged throughout the flue gas path. The increase in the volume of dry gases is due to the volumes of nitrogen and oxygen of excess air:

\[ V_{N_2} = V_{N_2}^0 + 0.79(\alpha - 1) \cdot V'_o \]  
(18) 

\[ V_{N_2} = 3.51 + 0.79(1.2 - 1)4.43 = 4.21 m^3 / m^3 \]  
(19) 

\[ V_{O_2} = 0.21(\alpha - 1) \cdot V'_o \]  
(20) 

\[ V_{O_2} = 0.21(1.2 - 1)4.43 = 0.19 m^3 / m^3 \]  
(21)
Consequently, the volume of dry gases can be recorded:

\[ V_{d.g.} = V_{R02} + V_{N2} + V_{O2} \]  
(22)

\[ V_{d.g.} = 0.99 + 4.21 + 0.19 = 5.39 \text{ m}^3 / \text{m}^3 \]  
(23)

Due to excess air, the volume of water vapor also increases somewhat:

\[ V_{H2O} = V_{H2O}^0 + 0.0161(\alpha - 1)v_0^0 \]  
(24)

\[ V_{H2O}^0 = 0.99 + 0.0161(1.2 - 1)4.43 = 1 \text{ m}^3 / \text{m}^3 \]  
(25)

Due to excess air, the volume of water

\[ V_w = V_{e.g.} + V_{H2O} \]  
(26)

\[ V_w = 5.39 + 1 = 6.39 \text{ m}^3 / \text{m}^3 \]  
(27)

The maximum normal flame propagation velocity (m/s) in a gas-air mixture can be determined by the formula:

\[ U_{a,n}^{\text{max}} = \frac{\Sigma C_m H_n - U_{c,H_n}}{\Sigma C_m H_n} \]  
(28)

\[ U_{a,n}^{\text{max}} = \frac{45 \cdot 0.37}{45} = 0.37 \text{ m/s} \]  
(29)

With the known content N\(_2\) and CO\(_2\), % vol., normal flame propagation speed \( U_{a,n}^b \), m/s for ballasted gases, correct by expression:

\[ U_{a,n}^b = U_{a,n}^{\text{max}} \left(1 - 0.01N_2 - 0.012CO_2\right) \]  
(30)

\[ U_{a,n}^b = 0.37(1 - 0.01 - 0.012 \cdot 52) = 0.14 \text{ m/s} \]  
(31)

It is known that the average value of the theoretically necessary volume of air for complete combustion of natural gas is about 9.85 m\(^3\), which, in comparison with the volume defined above, necessary for complete combustion of bio gas equal to 4.43 m\(^3\), in 2.2 times less. Thus, in gas burners for the combustion of bio gas the composition examined, this ratio must be observed.

The purpose of the gas burners is to organize the combustion of fuel in order to ensure a predetermined economically feasible operating mode of the boiler unit.

The gas burner achieves this goal by:
- Provision of supply and mixing among themselves the required amount of fuel and air;
- Organization of complete combustion of fuel within the boiler furnace space;
- Combustion of fuel in a mode that allows to ensure the level of heat transfer required in technological conditions in the working space of the boiler furnace.

Consequently, the entire cycle that makes up the process of burning the fuel (mixing-burning-heat transfer) must be performed with the highest efficiency of useful action [4].

The method of mixing gas with air is the main classification feature of burner devices and is divided into three groups:

- According to the main classification feature - the method of mixing gas with air, burners are divided into groups:
  - Complete pre-mixing of gas with air;
  - Partial premixing of gas with air;
  - Without premixing.

Given the low content of CH\(_4\) in biogas, it will be expedient to use a vortex-type burner with forced air supply and partial premixing of gas and air.

The merits of vortex burners include:
- Ability to work on low-calorie gas;
- Capacity control can be carried out in a wide range;
- The possibility of working in heated air.

To study the formation of a gas-air mixture, a computer model of a low-pressure vortex gas burner GGV-100 was developed [5]. The model is built using the Solid Works software complex, the gas dynamics calculations were performed by the Solid Works Flow Simulation module.

For the calculation, the following initial values of the parameters were chosen: dimensions correspond to the dimensions of the GGV-100 burner; gas flow at the burner inlet \( Gr = 0.027778 \text{ m}^3 / \text{s} (100 \text{ m}^3 / \text{h}); \)
air flow at the burner inlet $G_n = 0.123056 \, \text{m}^3/\text{s}$ (443 m$^3$/h); the roughness of the walls is $\Delta = 100 \, \mu\text{m}$; initial pressure in the combustion chamber $P_0 = 101325 \, \text{Pa}$.

Figure 1 shows a computer model of the GGV-100 vortex burner.

As a result of the calculation, the patterns of the change in the velocity of the gas-air mixture in the longitudinal-vertical plane of the section of the gas burner-furnace section shown in Fig. 2 and 3.

Analyzing the data obtained on the graphs, one can draw the conclusion that the velocity of the gas-air flow at the exit from the burner to the to-mail space occurs at a speed ranging from 11 to 17 m/s. At the same time, for the kinetic principle of combustion used by this burner, the rate of the expiration of the gas-air mixture from it during the combustion of a low-calorie gas must be taken at least 10-15 m/s. This condition must be met in order to avoid flashing the flame into the burner [4]. However, due to the relatively short length of the site with the optimal speed, the use of bio gas in the gas burner under test requires a detailed maintenance of the gas-to-air balance regime.
Conclusions. As a result of the study, a model for the distribution of a gas-air mixture in a vortex gas burner was developed using the program module Solid works Flow Simulation, taking into account the release into the furnace space. The distribution of the velocity of the gas-air flow was determined and a comparative picture of the change in the value of the velocity of the gas-air flow at different sections of the burner-furnace assembly was constructed. On the basis of the computer-aided model of aerodynamics of the GVV-100 vortex burner, it is possible to further improve and modernize gas-burning devices of this type.

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