Study of the speed of flame distribution in the combustion of methane-hydrogen fractions

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Abstract. At present, natural gas of the Urengoyskoye field is burned in boilers of thermal power plants (TPP) to generate electricity. At the same time, refineries and petrochemical plants deepen the processing of fossil liquid hydrocarbons. The final product of processing is not only motor fuels, ethylene glycols, plastics, accompanying inert gases such as argon, but also a large amount of combustible secondary gaseous mixtures of the methane series. These mixtures contain a wide array of combustible components. Among them there is the methane-hydrogen fraction, which is characterized by a fairly high hydrogen content. A distinctive feature of the use of hydrogen as a fuel is the high rate of flame propagation and the relatively low heat of combustion [1, p.6-8]. The methane-hydrogen fraction due to the volatility of the composition and a wide range of changes in the heat of combustion was recently used in refineries for their own needs as an insignificant additive to combusted natural gas in process furnaces [2-5]. If the methane-hydrogen fraction was not utilized as a fuel in these furnaces, it was burned in flares. Due to the increase in oil refining volumes and the increase in the amount of methane-hydrogen fraction produced, it became realistic to use this gaseous fraction as the main fuel for power boilers of thermal power plants located near petrochemical plants. In the near future, it is planned to use the methane-hydrogen fraction as an additive to the natural gas for 20 power steam boilers of the Nizhnekamsk CHP-1 with a total thermal capacity of 6000 MW. The supplier of the methane-hydrogen fraction is the TAIF NK oil refineries. Depending on the technology of oil refining, the hydrogen content in the methane-hydrogen fraction ranges from 10 to 27% (by weight). The concentration limits of hydrogen ignition in a mixture with air have been experimentally studied by many researchers [6–8] mainly during bench testing or inside laboratories. A feature of the oxidation of hydrogen by air oxygen is the fact that there is a difference between the spread of the flame in limited volumes and in large volumes of the furnace space of energy boilers [9]. In small volumes, when the flame front collides with the wall, oxidation reactions are interrupted, and this does not occur in large volumes. Therefore, the study of flame propagation speed and concentration limits of ignition of methane-hydrogen fractions mixed with air in relation to the conditions of furnace volumes of power boilers is relevant. In this work using the in-house software [2-5] calculations were made to determine the burning rate for various compositions of mixtures of methane-hydrogen fractions (MHF) with Urengoi natural gas. It was found that the flame propagation rate of the MHF, compared with hydrogen (see Table 2), decreases 1.76 times. For a mixture of the MHF with Urengoi gas with thermal fractions of the MHF of 12% and 25%, the flame propagation rate increases, respectively, 1.4 times and 1.78 times compared with burning pure Urengoi gas.

1 Introduction

The role of the methane-hydrogen faction (MHF) in the TPP fuel balance is currently growing as a substitute of the natural gas. This can be connected to deepening of the oil refining process and an increase of the share of light refining products in the output of oil refining factories, where the amount of excess MHF products has grown accordingly. The peculiarity of hydrogen oxidization reactions lies in the fact that there is a difference in flame spreading in limited volumes and in large volumes of power boiler furnaces [9]. In the small volumes when the flame front collides with the wall, oxidation reactions are interrupted, and this does not occur in large volumes. Therefore, the study of flame propagation speed and concentration limits of ignition of methane-hydrogen fractions mixed with air in relation to the conditions of furnace volumes of power boilers is relevant.

2 Description of an object and technique of a research

Data on the composition of the methane-hydrogen fraction (MHF) are obtained from the results of the

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analysis of the "TAIF NK" chemical laboratory. Data on the composition of the combusted Urengoi gas is obtained from the results of the analysis of the chemical laboratory of the Nizhnekamsk CHP-1. The choice of the heat share of the MHF, equal to 12%, in a mixture with combusted Urengoi gas is due to the design of the burners GMU-45 used in TGM-84B boilers. The heat share of the MHF of 25% in a mixture with Urengoi gas has been accepted as promising for burning in modernized burners of TGM-84B boilers. The calculation of the flame propagation speed and concentration limits of ignition was performed using the programs described in [2-5, 12-15].

In the Table 1 we list the composition of the methane-hydrogen fraction (MHF) in molar fractions in a mixture with Urengoi natural gas with a heat fraction in heat release of 12% and 25%.

The 25% mixture presented in Table 1 is planned to be burned in the furnaces of the TGM-84B boilers at the Nizhnekamsk CHPP-1 starting June 1, 2019.

3 The results of the study and their discussion

Maximum speed W_{mn} (cm/s) of the flame front propagation of a mixture of MHF and Urengoi gas when ignited in air at atmospheric pressure and at a temperature of 0 °C was calculated using the following formula:

$$W_{mn} = (m_1 \cdot W_{mn1} + m_2 \cdot W_{mn2} + \ldots + m_i \cdot W_{mni}) / \\ / (m_1 + m_2 + \ldots + m_i), \quad (1)$$

where m_i is the mole fraction (%) of the i-th component; W_{mni} is the maximum speed of flame propagation under normal conditions for the i-th component, cm/s.

The value W_{mn} is understood as the speed of propagation of the flame front in the normal direction.

The concentration limit of ignition (in%) of the mixture of MHF and Urengoi gas under normal conditions was calculated using the formula:

$$L_c = (m_1 + m_2 + \ldots + m_i) / \\ /(m_1/L_1 + m_2/L_2 + \ldots + m_i/L_i), \quad (2)$$

where L_{ni} and L_{vi} are the lower and upper concentration limit of ignition of the i-th component,%.

The values of the flame propagation velocity (cm/s) in air under normal conditions and the concentration limits of ignition (in%) of the individual components are given in Table 2.

As can be seen from the Table 2, the hydrogen flame propagation rate is 7.2 times higher than that of methane, which makes up 98% of the Urengoy natural gas composition. The limits of hydrogen ignition, compared with methane, are much wider.

In the Table 3 we show the results of calculation of the maximum flame propagation velocity and the concentration limits for igniting the mixture of Urengoi gas with the MHF when burning in air under normal conditions for the MHF heat release fraction of 12 and 25%.

As we can see from the Table 3, the speed of flame propagation of the MHF, compared with hydrogen (see Table 2), decreases 1.76 times. For a mixture of the MHF with Urengoi gas with the heat fraction of the MHF of 12% and 25%, the flame propagation rate increases, respectively, 1.4 times and 1.78 times compared with burning pure Urengoi gas.

To burn a mixture of Urengoi gas and the MHF with a 25% heat fraction of the MHF in TGM-84B boilers, modernized or special burners should be used, since due to the high propagation rate of the flames, the burning of the MHF in the horizontal gas duct of the TGM-84B boilers is inevitable. This will lead to an increase in the temperature of the combustion products in the horizontal gas duct, which, in turn, requires taking measures to

Table 1. Mole fraction (%) of the components m_i in the mixture of the MHF and Urengoi gas.

Components	**Formula**	**m_i mole fraction of components (%)**			
		MHF	**Urengoi gas**	**Mix with a heat share of the MHF 12 %**	**Mix with a heat share of the MHF 25 %**
Hydrogen	H_2	49.57	0	5.95	12.39
Methane	CH_4	30.48	98.84	90.64	81.75
Ethylene	C_2H_4	0.06	0	0.007	0.015
Ethane	C_2H_6	14.88	0.1	1.87	3.79
Propylene	C_3H_6	0.,01	0	0.0012	0.0025
Propane	C_3H_8	2.66	0.03	0.346	0.687
Butane	C_4H_{10}	1	0.02	0.14	0.265
Pentane	C_5H_{12}	0	0.01	0.009	0.0075
Hexane	C_6H_{14}	0.94	0	0.113	0.235
Nitrogen	N_2	0	0.7	0.616	0.525
Carbon monoxide	CO	0.06	0	0.007	0.015
Carbon dioxide	CO_2	0.1	0.3	0.28	0.25
Hydrogen sulphide	H_2S	0.0026	0	0.00032	0.00066
Water vapour	H_2O	0.24	0	0.029	0.06

Table 2. Values of flame propagation velocity Wmni (cm/s) in air under normal conditions and concentration limits of ignition (in %) of individual components [6-8].

Components	Formula	Maximum speed of flame propagation W_{mni}, cm/s	Concentration limit of ignition in air of the i-th component,%	
			lower L_{Hi}	lower L_{Hi}
Hydrogen	H_2	267	4	74.2
Methane	CH_4	37	5	15
Ethylene	C_2H_4	63	3.75	29.6
Ethane	C_2H_6	40	3.22	12.45
Propylene	C_3H_6	44	2.4	10
Propane	C_3H_8	38	2.37	9.5
Butane	C_4H_{10}	37	1.86	8.41
Pentane	C_5H_{12}	38.5	1.4	7.8
Hexane	C_6H_{14}	38.5	1.25	6.9
Carbon monoxide	CO	42	12.5	74.2
Hydrogen sulphide	H_2S	50	4.3	45.5

Table 3. The results of the calculation of the maximum flame propagation velocity and the concentration limits of ignition of the mixture of Urengoi gas with the MHF when burning in air under normal conditions for the heat release fraction of the MHF of 12 and 25%..

Components	Formula	Mole fraction mi (in%) of the i-th component			
		MHF	Urengoi gas	Mix with a heat share of the MHF 12 %	Mix with a heat share of the MHF 25 %
Hydrogen	H_2	49.57	0	5.948	12.393
Methane	CH_4	30.48	98.84	90.637	81.75
Ethylene	C_2H_4	0.06	0	0.007	0.015
Ethane	C_2H_6	14.88	0,.1	1.873	3.794
Propylene	C_3H_6	0.01	0	0.0012	0.0025
Propane	C_3H_8	2.66	0.03	0.346	0.687
Butane	C_4H_{10}	1	0.02	0.138	0.265
Pentane	C_5H_{12}	0	0.01	0.009	0.008
Hexane	C_6H_{14}	0.94	0	0.113	0.235
Nitrogen	N_2	0	0.7	0.616	0.525
Carbon monoxide	CO	0.06	0	0.007	0.015
Carbon dioxide	CO_2	0.1	0.3	0.28	0.25
Hydrogen sulphide	H_2S	0.00265	0	0.00032	0.00066
Water vapor	H_2O	0.24	0	0.03	0.06
Maximum speed of flame propagation, W_{mn}, cm /s		152	37	51	66
Concentration limits of ignition,%	lower	3.9	4,.992	4.83	4.66
	upper	22.48	14.99	15.62	16.36

prevent overheating of the metal superheaters and, as a consequence, to a decrease in the efficiency of the boilers. The fact of increasing the temperature at the outlet of the furnace when the MHF is burned mixed with Urengoi gas is confirmed by an examination of the raw material heating furnaces at the vacuum gas oil hydrotreatment unit at Ryazan Refinery OJSC [1].

4 Findings

1. The speed of flame propagation of the MHF, compared with hydrogen (see Table 2), is reduced by 1.76 times due to the presence in the MHF of a large amount of methane.

2. On the TGM-84B type boilers, when burning an MHF mixture with Urengoi gas with an MHF thermal fraction of 12%, burners of the GMU-45 type with

central gas distribution and peripheral tangential air twist can be used.

3.When the MHF heat content is 25% in the mix with Urengoi gas, the flame propagation rate increases by 1.78 times compared to burning Urengoi gas, and development of modified burners with combined peripheral tubular and central gas distribution and axial twisting air is necessary.

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