HEAT TRANSFER OF A GAS FLAME WITH DIFFERENT DEGREES OF PREMIXING

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Results are presented of an experimental investigation of the total thermal emission, radiative and convective of a natural gas flame in a water-cooled combustion chamber, at various degrees of premixing with air.

In furnace design the mode of combustion of the gas is of special importance. Combustion of the same amount of gas in a furnace may be effected in flames of different types ranging from short and transparent to long and luminous flame is obtained when the gas is well mixed with air before the start of combustion (in the mixers of injection burners kind possesses known advantages, since it permits reduction of the required height of furnace and the achievement of complete combustion of the gas under conditions of minimum excess of air, and of practically complete absence of heat loss from chemical incompleteness of combustion ($q_z < 0.01\%$).

Although a number of papers on this subject have been published [1–5], there are no data on comparative heat emission of a gas flame, for a definite degree of premixing of gas and air.

The heat emission from a gas flame was investigated in experimental equipment (Fig. 1) whose combustion chamber was a vertical calorimeter with internal diameter 51 mm and height 550 mm, composed of five separate sections connected in series. The water temperature at the inlet and exit of each section was measured with thermometers graduated in 0.1° C.

Natural gas and air were fed into a mixing burner with a head in the form of a cone whose base was a plate 30 mm in diameter with 120 apertures 1 mm in diameter, which ensured stable combustion and precluded flashback. The burner was inserted from below into the combustion chamber-calorimeter (the top part of Fig. 1 shows a separate illustration of the fitting of the burner into the combustion chamber-calorimeter) and had a special disk for controlling the inflow of secondary air. The mass flow rate of the gas remained constant. The thermal load of the combustion chamber-calorimeter was 1785 kW/m^3.

The degree of premixing of the gas with primary air, α_p, in the burner mixer was set at 0.2, 0.4, 0.6, 0.8, and 1.0, in turn; control was accomplished by determining the oxygen content of the gas-air mixture withdrawn from the head of the burner. No tests were carried out with $\alpha_p = 0$ because of the impossibility of securing complete combustion in the small chamber, and also because of the considerable deposition of soot on the chamber walls.

For a specific degree of premixing of the gas with primary air, the total air-fuel ratio, α, was varied from 1.0 to 1.5 by inflow of secondary air into the chamber (by drawing it through the adjustable annular section formed by the lower face of the chamber and a special burner disc and computed from the composition of the combustion products at its exit, and from analytical determination in VTI-2 apparatus and a KhT-2M chromatograph.

The overall thermal efficiency of the chamber was determined by the relation

$$\mu = Q_w / BQ_H^p \eta_H, \qquad (1)$$

where

$$\eta_H = 1 - q_z/100. \qquad (2)$$

The results of the experiments are presented in Fig. 2 and in the table. It may be seen from the figure and the table that, with decrease of α_p from 1.0 to 0.2 (corresponding to change of the configuration and the state of the flame from nonluminous, consisting of fine transparent flames of height 15–20 mm with $\alpha_p = 1.0$, to a yellow luminous flame of height 200–250 mm with $\alpha_p = 0.2$), heat transfer decreases by 20%, for constant gas flow rate and for $\alpha = 1.0$.

It is known that a natural gas flame has a higher temperature when there is complete premixing of the gas with air. The mean temperatures of the flame in the chamber for various α_p fell in the range 1200–1600° K, the flame temperature decreasing with decrease of α_p, and its maximum was displaced upwards along the

Values of Over-all Thermal Efficiency μ (the figures in brackets are expressed as a percentage of the value of μ with $\alpha = \alpha_p = 1.0$)

Air fuel ratio α	Degree of premixing α_p (as a fraction of the amount of air theoretically required)				
	1.0	0.8	0.6	0.4	0.2
1.0	0.544 (100.0)	0.532 (97.8)	0.516 (95.0)	0.476 (87.5)	0.436 (80.2)
1.05	0.532 (97.8)	0.520 (97.7)	0.492 (90.4)	0.446 (82.0)	0.421 (77.4)
1.10	0.525 (96.5)	0.510 (95.6)	0.482 (88.5)	0.434 (79.8)	0.414 (76.2)
1.20	0.518 (94.1)	0.503 (91.2)	0.473 (85.7)	0.426 (77.2)	0.409 (74.3)
1.30	0.500 (91.9)	0.484 (89.0)	0.458 (84.3)	0.413 (76.0)	0.398 (73.2)
1.50	0.480 (88.2)	0.464 (85.4)	0.433 (79.5)	0.403 (74.2)	0.390 (71.7)

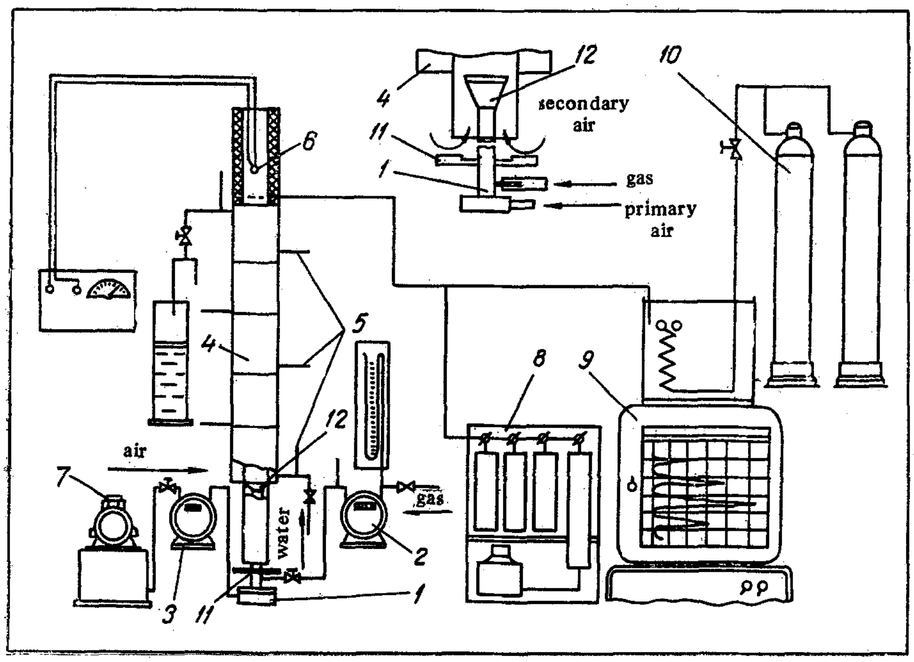

Fig. 1. Experimental equipment for investigation of the influence of the degree of mixing of gas with air on heat transfer: 1) gas burner; 2) gas flowmeter; 3) air mass flowmeter; 4) combustion chamber-calorimeter; 5) thermometers; 6) thermocouples; 7) compressor; 8) VTI-2 gas analyzer; 9) KhT-2M chromatograph; 10) bottle of carrier gas; 11) control disc; 12) gas burner head.

axis of the flame, falling in the regimes with $\alpha_p = 1.0-0.8$ in the region of the first section, with $\alpha_p = 0.6$ in the second section, and with $\alpha_p = 0.4-0.2$ in the third section of the chamber. The flame temperature was measured with a chromel-alumel thermocouple, the diameter of the exposed junction being 1 mm, inserted into the flame from above along the axis of the chamber, thus permitting a qualitative estimate of the position of maximum temperature in the flame, although the determination of absolute temperatures was inaccurate.

The distribution of maximum values of μ across sections of the chamber (Fig. 3) agrees with the position of maximum temperature in the flame in the regimes with corresponding values of α_p.

The data (table, Figs. 2 and 3) show that under the low-temperature conditions ($T_f = 1200-1600°$ K) prevailing in water-cooled combustion chambers, the value of μ for a nonluminous flame with complete premixing may exceed that for a luminous flame by a margin of 20%.

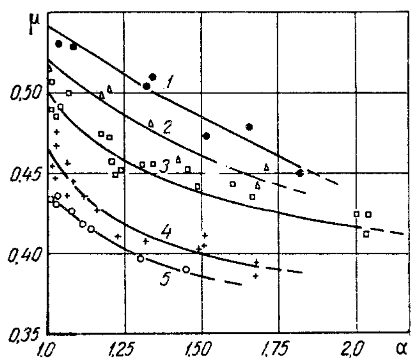

Fig. 2. Dependence of μ on the degree of premixing and dependence of air-fuel ratio: 1) for $\alpha_p = 1.0$; 2) 0.8; 3) 0.6; 4) 0.4; 5) 0.2.

In combustion chambers with a higher temperature level, the difference in heat transfer between the nonluminous and the luminous flames decreases and has smaller values in actual furnaces [5].

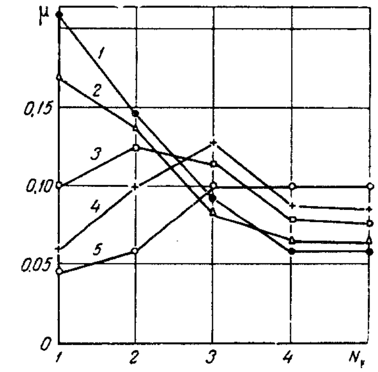

Fig. 3. Distribution of heat transfer over sections of combustion chamber-calorimeter, with $\alpha_p = 1.05$: 1–5) see Fig. 2.

NOTATION

α_p is the degree of premixing of gas and air; α is the air-fuel ratio; μ is the overall thermal efficiency of combustion chamber-calorimeter; Q_w is the heat absorbed by the water in the combustion chamber-calorimeter; B is the gas mass flow rate adjusted to standard conditions; η_H is the heat release factor; Q_H^p is the calorific value of gas; T_f is the flame temperature; q_z is the heat loss due to chemical incompleteness of combustion at the end of the combustion chamber-calorimeter; N_C is the calorimeter number (beginning at burner).

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