(oxidant); F, geometric-mean value; g, gas layer; 1, 2, "cold" and "hot" surface of permeable wall, respectively; 3, surface of heated part; ∞, value as $y \to \infty$; ε, value as $y \to -\infty$; I, initial; U, ultimate.

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DEVELOPMENT AND BURNOUT OF A FLAME IN A PLANE-FLAME BURNER

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The features of the formation, development, and burnout of a flame in a plane-flame burner are established. The optimal conditions of burner use, at which the fuel-component content in the combustion products is within normal limits, are determined.

In the heat treatment of surfaces in various technological processes, use is made of gas-burner devices forming flames in basically conical form; considerable flame length and width of the reaction region are characteristic of these devices. It is known that heat-exchange processes in the interaction of an open flame with the surface depend on the magnitude of its thermal stress, which, in turn, is determined by the flame length and the thickness of the reaction region [1]. According to the investigations of [1], decrease in reaction-region thickness leads to decrease in flame length and increase in thermal stress. On the basis of these conclusions, an injectional slit gas burner was developed [2]; in this burner, the gas burns in a plane flame of comparatively small length.

Below, the processes of flame formation and burnout of gas–air mixtures in atmospheric conditions are analyzed.

The investigation was conducted for a burner designed for the ignition of 0.5-1.7 m^3/h of the vapor phase of liquified gas (50% propane and 50% butane, percentage by volume) at pressures at 10-110 kPa, with structural elements of the following dimensions: mixing-chamber diameter $d_{mi} = 0.05$ m and length $l_{mi} = 2.5d_{mi}$; diffusor length $l_D = 4d_{mi}$ and aperture angle 60°; height of slit in aperture $h_S = 0.006$ m and slit length $l = 50h_S$. The features of flame development were investigated in isothermal conditions by the method of [3]. From the distribution of the dynamic head in the flame, which was measured by a three-channel cylindrical probe with blowing of air through the burner, the aerodynamic axis of the flame, the aperture angle, and the velocity attenuation were determined.

In Fig. 1 (curve 1), in dimensionless coordinates, the resutls of measuring the relative dynamic head h_D/h_D^{max} as a function of the dimensionless flame length L/h_S are shown. Extinction of the jet is observed at $L/h_S = 50$, i.e., at a distance equal to the flame-front length. The aperture angle of the flame was determined by measuring the dynamic head in the profile plane at a distance from the burner slit of 0.03 m. The dynamic head h_D was measured at points in the axial and peripheral planes of the flow. At a distance of 0.01 m from the axial plane, the ratio $h_D/h_D^{max} = 0$. This parameter determined the aperture angle of the flame in the plane of reaction-region thickness, which was obtained by calculation, taking the geometric dimensions of the burner slit into account, and was found to be 10-13°.

In exothermal conditions, the degree of burnout of the flame, the temperature distribution over its length, and the composition of the combustion products were found.

The degree of burnout of the flame was estimated from the content of carbon dioxide in the combustion products as a function of the relative distance from the burner slit. In

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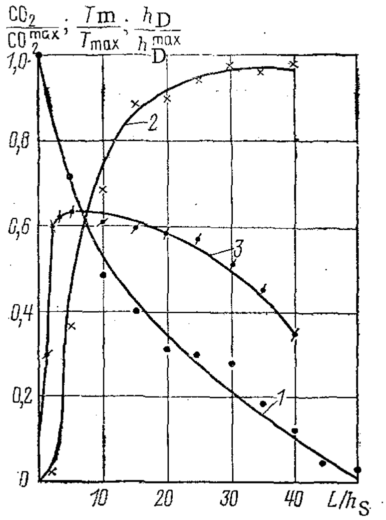

Fig. 1. Dependence of the dynamic head (1), degree of burnout of the gas (2), and mean temperature (3) on the relative flame length.

Fig. 1 (curve 2), in dimensionless coordinates, the results of the measurements are shown in the form of the dependence $CO_2/CO_2^{max} = f(L/h_S)$.

In stoichiometric conditions of combustion, the maximum CO_2 content in the combustion products of a propane–butane (1:1) gas is 13.9% [4]. Analysis of the graphical dependence shows that C_{CO_2} does not reach its maximum. However, the combustion process is practically ended at a distance $L = 40h_S$. The aerodynamic length of the flame, defined as the distance along the geometric axis of the flame from the slit to the cross section of the flow in which the maximum value of the local velocity is 15-20% of the flow-average at the slit, also lies within this range.

One of the main indices determining the efficiency of ignition of the gas is the flame temperature. In measuring the flame temperature, a platinum–platinorhodium thermocouple with a 0.3-mm electrode diameter was used. The thermocouple junction of 1-mm diameter ensured low inertia of the measurement process and did not induce perturbations in the flow. The distance from the thermocouple junction to the holder was 35 mm, which allowed the error introduced by heat conduction and heat transfer between the electrodes and the holder to be eliminated. The thermocouple junction was screened so as to prevent loss by radiant heat transfer. The free ends of the thermocouple were thermostatted at 0°C. The emf was measured by a UNIP-60m universal potentiometer. The flame temperature was determined in the flow cross section of the slit and in the direction of flame development. In Fig. 1 (curve 3), in dimensionless coordinates, the change in mean flame temperature is shown in the form of the dependence $T_M/T_{max} = f(L/h_S)$, where $T_{max} = 2114$°C is the theoretical combustion temperature for a gas of the given composition. The measured temperature value in the flame core reaches 1350°C and decreases with increase in its relative length.

The parameters shown in Fig. 1 determine the qualitative structure of the flame. The region of maximum velocities and minimum temperatures may be attributed to the region of ignition of the gas–air mixture, which lies in the range $L/h_S = 0\text{-}2.5$. The active-reaction region $L/h_S = 2.5\text{-}5.0$ includes the maximum temperature range. In this region, the CO_2 content does not reach a maximum, and hence it is characterized by an elevated carbon monoxide content. The region $L/h_S = 30\text{-}40$ is distinguished by a sharp reduction in combustion-product temperature and an increase in the CO_2 content and is the region in which the combustion of the fuel components is completed.

Balance experiments conducted using the GKhP-3M and VTI-2 gas analyzers to determine the efficiency of gas ignition in the given burner allowed the optimal conditions of burner operation to be established. To this end, for six values of the excess gas pressure within the limits of stable operation of the burner, the concentrations of oxygen in the gas–air mixture and also of CO_2, CO, H_2O, and O_2 in the combustion products were determined. The points of gas-sample withdrawal were chosen in accordance with the procedure of control testing of industrial gas-burner devices [5]. For a given burner sample, this point is at a distance of 0.2L from the end of the flame. The results of the measurements are shown in Fig. 2, in the form of graphical dependences of the excess-air coefficient, the CO_2 and CO concentrations, and the gas flow rate on the excess gas pressure in front of the nozzle.

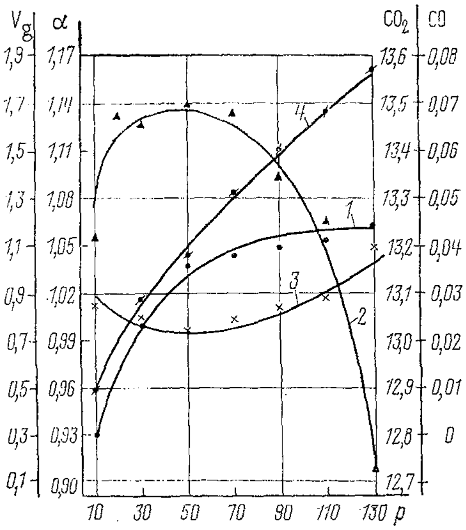

Fig. 2. Dependence of the excess-air coefficient α (1), the CO_2 (2) and CO (3) concentrations (vol. %), and the gas flow rate V_g (m^3/h) (4) on the excess gas pressure p, kPa, in front of the nozzle.

Consideration was given to optimal conditions of operation of the given burner with preliminary complete mixing, when the excess-air coefficient $\alpha = 1.03$ ensured an excess-gas pressure of 50 kPa and a flow rate of 1.08 m^3/h. The given α was obtained as a result of measuring the oxygen concentration in the mixture at the outlet from the slit. From the theoretically necessary amount of air for ignition of a gas mixture of the given composition (27.34 nm^3/nm^3), the volume of gas–air mixture admitted to the reaction region (31.49 m^3), and the actual value of the injection coefficient ($A = 28.16$ nm^3/nm^3) were calculated. Analysis of the combustion-product composition in these conditions revealed the presence of the following components in the mixture, as recalculated per m^3 of ignited gas: $CO_2 = 3.3$ m^3, $CO = 0.0069$ m^3, $O_2 = 0.18$ m^3.

From the volume and percentage content of dry combustion products, the volume of aqueous vapors H_2O was calculated (4.0 m^3). From the value of the injection coefficient, the amount of oxygen admitted to the reaction region was calculated: $V_{O_2}' = 0.21$, $A = 0.21 \cdot 28.16 = 5.92$. In the course of the reaction, the following amount of oxygen is consumed in the formation of CO_2, CO, H_2O (taking excess O_2 into account): $V_{O_2}'' = 3.3 \cdot 0.73 + 0.0069 \cdot 0.57 + 4.0 \cdot 0.81 + 0.18 = 5.83$ m^3. Thus, $V_{O_2}' \approx V_{O_2}''$. The slight discrepancy between the values obtained (+1.5%) indicates the reliability of the measurements made, the analysis of the reaction products, and the calculations. The 0.0069-m^3 CO content in the combustion products amounts to 0.022% of their total volume. This value lies within the limits of the SNIP norm for general-purpose burners [6].

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