Oscillating Conditions and Quenching of inverse Gas Flame in passing Flow

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1 Introduction

The investigations [1,2] of the dimensional chemical and heat structure of the flame are interest for development the detal kinetic mechanizms of combustion. The actuality of the study of the inverse flame and inverse overturned flame is connected with the features of the gas velocity pofiles and the heat and mass-transfer rates of these flames.

In this paper the role of the vortex structure formation under the ifluence of the free convection is studied. There are the tangential heat fluxes directed to the base of the flame front cone. It is known that these ones are directed to the top of the cone in the Bunsen-type flame. The temperatute maximum of the inverse flame is also displaced from the central part of the stream. The velocity profile in the inverse flame overturned relatively the vector of the gravity assists in the formation of the spontaneous vortex structures in the stream. These factors determine the intensity of the heat change between the flame and the wall of the combustion chamber. But the conformities to natural laws of hydrodynamics and heat and mass transfer in the inverse and overturned flames are not still studied. There are not any publications dedicated to the inverse flame in the pasing flow near the interminable and thin stabilizator.

If the inverse flame is overturned the interval of the stable combustion increases again. The instability of the inverse flame becomes apparent at first as the small oscillations of the peak of the cone. Then the oscillations increase and the flames vibrates as the whole. The role of the thermoconductive stabilizer in the mechanizm of the instability and quenching of the inverse flames is investigated.

The increase of the amplitude of the oscillations is accompanied by quenching of the flame. Before quenching the flame front is falled to pieces. Every piece of the flame can exist for definite time. This stage of the process of quenching can be used for its prediction.

The changes of the temperature field in the flame caused by the hydrodynamical situation often are not great. But the tangential temperature gradients are considerable. The problem of contactless diagnostics and precise measurements of the temperature and concentration fields is still important at present [3]. All these problems define the objects and purposes of the work.

2 Experimental part

The experimental setup consisted of the burner, stabilizer, systems of vizualization and measuring. The burner was a cylindrical tube. The inernal diameter of the tube was changed from 3 mm to 15 mm. The stabilizer was a wire established inside the burner on the axis of the tube. The diameter of a wire also was changed from 0.5 to 4 mm. The position of the short stabilizer above the edge of the burner was changed from 5 to 25 mm. The combustion of propane-air mixtures in inverse flames was investigated. The inverse flame was obtained by increasing the gas velocity. If the normal velosity of the flame front propagation is leess then gas velocity on the edge of the burner, the Bunsen flame was inverse and the location of the inverse flame on the wire was controled. The position of the inverse flame on the stabilizer determined the shape, side of the flame and its temperature and velosity fields. The combustible mixtures were prepared in gasometer. The volume expenses were measered by rotameters and using the overfall of the pressure on the calibratedcapillary.

The measured parameters of the flame were its size and distributions of the velocities and temperature. For this purposes the images of the luminescence and photometrical images of the flame were obtained by using the digital camera. The method of the digital photometry for the temperature measuments was developed. The measurements of the temperature were duplicated by the pyrometry and thermocouple methods. The velocity distributions were studied by the method of the luminescent tracks.

Besides, the evolution of the acoustic oscillations was studied. The oscillations of the flame were initiated in definite interval of Reynolds numbers. The other determining reason of the excitation of the oscillations is the direction of the stream relatively the gravity vector. The amplitude of the flame oscillations was measured using images of the flame. The frequency and amplitude of the oscillations of the pressure were fixed and studied by the sensing elements and oscillograph. The increase of the amplitude of oscillations was accompanied by the derangement and quenching of the flame. Quenching of the flame was observed also at some relation between the diameter of stabilizer, burner and heat power of the flame.

The capillar tube was used as a stabilizer for measuring the heat fluxes to its surface. The water was running through the tube from the lower to upper end of the stabilizer. The measurements of the intensity of the heat transfer near the stabilizer surface were made by the standard method of the heat balance.

3 The method of digital Photometry for Diagnostics of Flame

The method of digital photometry can be applied for several kinds of the optical heterogeneities. The examples of the transparent optical heterogeneities are the electric discharges, luminescence and fluorescence of flames of gases or condensed fuels. The object of the study in this work was an inverse flame established at a long or short wire.

At present there is a whole complex of the software, allowing to obtain the distribution of amplitude of the light beam on CCD-matrix of a digital camera. The photographs of luminescence and the photometric images of the flame established on a long or short wire are presented in the paper. The photometric image are obtained using the images processing program «GIMP 2.2» and correspond to a pictures of integrated luminosity isolines of the flame.

The photometric image looks like an interference picture of a flame. Every line of the photometric image corresponds to the certain value of the integral luminosity power of the flame. In this connection, it is convenient to use the term «the order of a photometric line» at processing of the photometric images as well as at the description of the interference pictures. The order of interference is determined by the local values of such parameters as the light refraction and the geometrical length of the beam way in optical heterogeneity, i.e. optical length. The integral luminosity also depends on the geometrical length of the beam way and the local luminosity. The order of a photometric line, i.e. the number of a color line is counted from the external edge of the image. The benefit of the method of digital photometry is in the possibility of determining of the distribution and absolute values of the integrated luminosity of the flame inside the investigated section of a flame.

It is possible to consider the optical heterogeneity to be thermal and radiating. The luminescence of the flame is caused by radiation of the soot particles. For the most hydrocarbonic flames the soot particles with the great accuracy can be approved as absolutely black body and it is possible to use Stephan-Boltzmann law, connecting integrated luminosity of radiating object with its temperature. Absolute value of the integrated luminosity power usually remains unknown in the conditions of the experiment. Its value was obtained by the experimental way on known value of the temperature in some point. For example, it was easy to obtain the temperature near the hot stabilizer, in the inverted flame. For this purpose were made the temperature measurements on the surface of the stabilizer, with the help of the thermocouple or an optical pyrometer [4]. Then it was possible to establish connection between the distribution of the local luminosity power and the temperature.

4 The mathematical model of the inverse flame

The mathematical model of the inverse flame was developed using the system of the two dimensional and axisymmetrical equations of motion, diffusion and energy in the boundary layer approximation. The velocity, concentration and temperature were unknown functions of radius of the jet and height above the edge of the burner. The boundery conditions for the temperature, velocity and concentration on the stabilizer and on the edge of the jet were formulated. The solutions of the equations represented in the work [5] were applied. The solution of the equation which takes into account the influence of the gravity was obtained. The numerical decisions of the differential equations were made by using standard software.

The condition of very long and thin stabilizer and the condition of thin and short stabilizer were examined. The velocity distributions in the sream using these solutions were calculated. The location of the front of the inversed flame was determined as a surface, where the normal velocity of the flame front is equal to the velocity of the stream. The value of the normal propagation velocity of the flame was corrected on each step of calculation, because it depends on the values of concentration in the point.

The comparison of the images of the flame observed in the real experiments and the results of the calculations shows that they are in good accordance. The mathematical model allows to predict the posible versions of the formation and evolution of the flame surface under change of the velocity value of the stream and its direction relatively the gravity vector.

5 Results

It was found that there are stable and instable states of the inverse flame. The stability of the flame is determined by two parameters. One of them is Reynolds number, the other one is the coordinate of the flame above the edge of the burner. There are not linear dependences of Reynolds number and the coordinate of the flame on the composition of the combustible mixture. The stability of the inverse flame behind the stabilizer of limited length is disturbed at Reynolds numbers less than 150. The inverse flame in the pasing flow near the interminable stabilizer is more stable. The interval of Reynolds numbers, which provides the stable combustion, increases to 300. The shape of the flame front becomes very complex.

It is shown that the inverse flame can move along the stabilizer. The position of the flame depends on the velocity of the stream in the jet. There is the simple accordance between the coordinate of the flame and beginning of its instability. All these dependences are different for the inverse flame and the inverse and overturned flame. The great role in the formation of the structure of the inverse flame plays the free convection. There is the definite dependence of the instability intervals on Rayleigh and Reynolds numbers.

The instability becomes apparent when the oscillations of the flame develop. The cone of the flame front falls to two cones at definite value of the oscillation amplitude. The dependence of the frequency of oscillations is also not linear function of Reynolds number. The next stage of the instability evolution is quenching. The study of the temperature field of the flame by the method of digital photometry shows that the maximum of the temperature decreases and displaces to the base of the cone of the flame front if the inverse flame is not overturned. In case of the inverse and overturned flame the maximum of the temperature displaces to the peak of the conical flame front. The amplitude of the oscillations of inverse and overturned flame is less than this one of the just inverse flame.

It is found that the role of the thermoconductive stabilizer changes if the inverse flame is overturned. The boundaries of the stationary states of the combustion become wider if the inverse flame is overturned and the diameter of the stabilizer is less than the critical value.

6 Conclusions

The free convection determines the process of the vortex structure formation in the inverse flame. The swirl motion of the gas in the vortex structure increases the intensity of the heat and mass-transfer between the flame and the walls of the combustion chamber. Sometimes it provokes exciting the acoustic oscillations of the flame or its derangement and quenching.

Quenching of the inverse flame is stipulated mainly by the convective mechanism of the heat losses to the ambient air. If the inverse flame is overturned the heat losses to the stabilizer define the process of quenching. The conductive mechanism of quenching is primary if the diameter of the stabilizer is greater than critical one.

The amplitude of acoustic oscillations is also controlled by the free convection and the vortex flow. The frequency of the oscillations depends on the size of the stabilizer. It is a function of Rayleigh and Reynolds numbers. There is an area of the stable combustion as a function of Rayleigh and Reynolds numbers.

The laws of the formation of inverse flames and heat and mass transfer allow to design the new effective combustion chambers.

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