STUDIES OF COMBUSTION AND HEAT-TRANSFER PROCESSES IN A COMBUSTION FLAME IN A MELT

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With a specially developed zonal mathematical model theoretical studies of heat transfer processes in a combustion flame immersed into a melt were carried out in steady-state conditions. As a result of this analysis, including the main phenomena which take place in gaseous fuel burning in the melt, the temperature and heat flux distributions between different phases over the melt height were found. The effect of convective heat transfer on the heat-transfer processes between the melt and the immersed combustion flame was determined.

At present, natural gas burning in a melt is widely used in metallurgy for heating and implementation of different production operations. Therefore, solution of problems concerning heat transfer between the melt and an immersed combustion flame seems important. Processes which take place in the interaction of the flame and melt are of a very complicated nature, and their experimental investigation is extremely difficult. Therefore, it is reasonable to investigate these processes with mathematical simulation methods.

The zonal mathematical simulation methods used in this study prove useful in simulation of flame processes in commercial heating and melting units, where radiative and convective components of heat-transfer and combustion processes and other complicated conditions must be taken into consideration.

The relevant publications [1, 2] concentrate mainly on heat transfer from the bubbled melt to the walls; in [3] a theoretical analysis of convective heat transfer from emerging gas bubbles developed in methane burning in slag is carried out where the influence of individual effects on the efficiency of the heat process are included.

The goal of this study is to investigate combustion and heat-transfer processes of a combustion flame immersed into a melt with zonal mathematical simulation methods in steady-state conditions.

In developing the calculation procedure, the known theoretical assumptions typical of the zonal calculation method [4] were used. In the zonal calculation method, it is assumed that the object model can be divided into separate zones with energetic (temperature and heat flux density) and optical (emissivity and absorption coefficient) characteristics independent of the coordinates within each zone.

To solve the problem, a zonal mathematical model of part of the immersed combustion flame was developed.

The mathematical model is a parallelepiped divided along its height into ten levels, each containing a volume gas zone, volume melt zone, and phase interface zone through which heat transfer between the gas phase and melt is realized. The geometry of the zonal mathematical model is given in Fig. 1.

In the model developed, the most important factors which influence the gaseous fuel combustion processes in the melt were considered, as well as the volume and surface of the bubble combustion products developed in fuel burning and ascending through the melt layer. Mass transfer in the gas phase and heat transfer from the gas phase to the interface by radiation and convection with regard to gas dissociation at high temperatures were considered. In heat transfer from the interface into the melt, the corresponding convective heat transfer coefficients were considered. To complete the heat transfer between the gas phase and melt it is assumed that the interface thickness is infinitesimal and the whole heat flux from the gas phase across the interface goes into the melt.

The following initial values were taken for the calculations. The natural gas consumption for the basic calculation version is 62.5 m^3/h with an oxygen consumption factor of 1.11. The gas calorific power is 35.4 MJ/m^3. The total surface of the produced gas phase was calculated to be 6.61 m^2 (heat-transfer surface). It was assumed that the whole radiation

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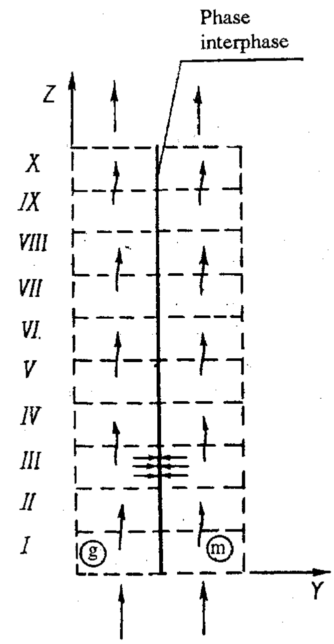

Fig. 1. Geometry of the zonal mathematical model of the combustion flame immersed into a melt. I-X) levels of the model division along the height; g, m) volume zones of the gas phase and melt.

of the combustion product inside the volume gas zone was concentrated on the adjacent phase interface. There was no radiation heat transfer between the other zones. For transparent melts the procedure allows the longitudinal radiative fluxes to be taken into consideration. The convective heat-transfer coefficient from the gas phase to the phase interface was determined from the expression for heat transfer from the interior of spherical bodies to their surfaces [5] and was 5-15 W/(m^2·K) for the conditions of this problem. The relation defining the convective heat-transfer coefficient for the flow around spherical bodies [5] was used to determine the convective heat-transfer coefficient from the interface to the melt; this factor was found to be 1000-2000 W/(m^2·K). Since it is very difficult to determine the interface area and convective heat-transfer coefficients, the complex αF was used in the calculations as a parameter which characterizes convective heat transfer from the interface to the melt, which under the present conditions was 660-1320 W/K inside a single surface zone. It was assumed that fuel combustion took place in the vicinity of the lance outlet section at a depth of 1 m from the melt surface. The latent dissociation heat of high-temperature combustion products was included in the calculations. On equilibrium composition the dissociation in the combustion zone was 50% (at a gas temperature of 2873 K). In accordance with the concept of heat transfer in dissociated gas it was assumed that the latent dissociation heat was released on the interface. A constant melt temperature of 1773 K over the melt height was assumed.

Figure 2 shows some calculation results. In Fig. 2a, the calculated curves of the gas phase and interface temperature variations are shown. Gas phase and interface temperatures decrease abruptly as the melt layer thickness decreases. This suggests intensive heat transfer between the gas phase and melt. Heat-transfer processes are practically completed at a distance of 0.6 m from the entry of the fuel−oxygen mixture. At a height of more than 0.6 m the gas phase and interface temperatures reach the melt temperature. Heat transfer between the gas phase and melt is most intensive at the first melt level (at the point of the heat-transfer agent entry). Due to emission of the latent dissociation heat on the interface, the specific heat flux from the interface into the melt differs from the specific heat flux from the gas phase by a value of the latent heat of dissociation (see Fig. 2b).

Analysis of the influence of αF on heat transfer between the gas phase of the immersed combustion flame and the melt was carried out. As was noted above, this complex characterizes convective heat transfer from the interface to the

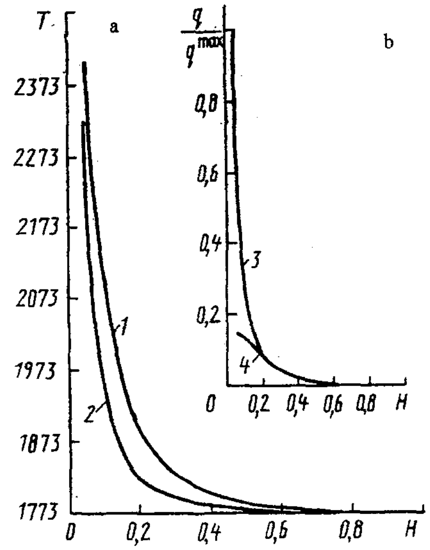

Fig. 2

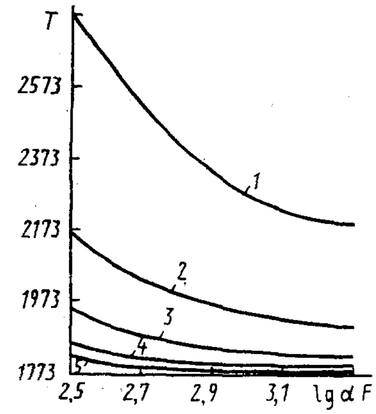

Fig. 3

Fig. 2. Variation of temperature (a) and specific heat flux (b) over the melt height: 1) gas phase temperature; 2) interface temperature; 3) specific heat flux from the interface into the melt; 4) specific heat flux from the gas phase to the interface. T, K; H, m.

Fig. 3. Variation of the gas phase temperature at different melt levels vs complex αF: curves 1-5 correspond to melt levels I-V.

melt. In Fig. 3 the results on the effect of the complex αF on the gas phase temperature at different model levels are shown. As the complex αF increases, the gas phase temperature at each level decreases in such a manner that the larger the complex αF, the smaller its influence on the gas phase temperature variation (the curves are decaying).

The zonal mathematical model of a combustion flame immersed into a melt was developed to investigate steady-state combustion and heat-transfer processes. Theoretical calculations were carried out to investigate the distribution of phase temperatures and heat fluxes over the melt height. The effect of the convective heat transfer rate from the interface to the melt was considered. The results can be used in studying processes in which an immersed combustion flame is used to heat the melt and to realize different production operations in it.

NOTATION

α, convective heat-transfer coefficient W/(m^2·K); F, interface area, m^2.

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