In conclusion, we comment briefly on the choice of parameters appearing in the formulas.

The value of R depends strongly on the angle of incidence of the radiation on the phase boundary. Since for radiation heat transfer inside a material the rays are incident on the surface at very different angles, the value of R in the equations must be replaced by its average value, the hemispherical reflection coefficient. Since diffraction effects are not taken into account in calculating K_e by the proposed model, Eqs. (3)-(10) should be applied only to particles which are much larger than the wavelength corresponding to the maximum of the thermal radiation at the given temperature.

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INVESTIGATION OF THE HEAT AND MASS TRANSFER BETWEEN PROPELLANT COMBUSTION PRODUCTS IN AN EVAPORATING FLUID IN APPARATUS WITH SUBMERGED BURNERS

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Generalized dependences are found to determine the equilibrium depth of submersion of a burner in evaporators with submerged burners.

Apparatus with submerged burners (ASB) are among heat exchangers of bubble type, in which the heat-exchange intensity is ordinarily characterized by the heat-elimination coefficient referred to the volume of liquid or gas — liquid layer above the grating. In connection with the fact that the ASB operates in a thermal equilibrium mode between the fuming gases leaving the apparatus and the evaporating liquid, these volumes can significantly exceed the volume of the active heat and mass transfer zone. Hence, the volume coefficients of heat elimination do not characterize the kinetics of the process in an ASB. Under these conditions, the main parameter to be determined for the heat and mass transfer process becomes the magnitude of the equilibrium depth of burner submersion at which thermal equilibrium sets in. The more intense the heat transport, the smaller the equilibrium depth of burner submersion, and, therefore, the lower the hydraulic drag of the apparatus.

On the basis of an analysis of the differential equations describing the heat and mass transfer in a gas — liquid layer, and the heat balance — heat elimination equation, the general form of the functional dependence for the equilibrium depth of burner submersion h_e [1] was found:

$$\bar{h}_e = \frac{h_e}{d} = c\,\mathrm{Ar}^m \Theta^n \left(\frac{\rho''}{\rho'}\right)^p \left(\frac{l}{d}\right)^q. \tag{1}$$

The thermal equilibrium can be estimated by means of the temperature of the vapor — gas mixture leaving the apparatus, which diminishes with the increase in depth of burner submersion and takes on a constant value when

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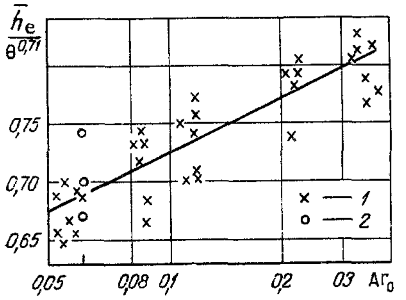

Fig. 1. Generalization of test data to determine the equilibrium depth of burner submersion: 1) water; 2) water solution of ammonium sulfate.

the depth of submersion becomes equal to or greater than the equilibrium value. Analytic and experimental studies have shown that the temperature is related to the depth of burner submersion by an exponential dependence. Assuming the exponential function to reach the steady-state value for 99% of the magnitude of this function at infinity, an equation was obtained which permitted computation of the quantity h_e by means of three values of the temperature of the departing vapor – gas mixture, determined experimentally, which corresponded to three discrete depths of burner submersion [2].

In connection with the essential dependence of h_e on the construction of the bubble apparatus, experimental investigations were performed in an apparatus with a tubular bubbler in the form of a burner lowered into a liquid with a bubble grating mounted at the level of the burner nozzle exit, and with a circulation tube arranged around the lower part of the burner. Experimental points obtained in an investigation of the equilibrium depth of burner submersion in an apparatus with a tubular bubbler are presented in Fig. 1. The tests were conducted in water and a water solution of ammonium sulfate of density 1250 kg/m³. The results of the investigations are generalized by the equation

$$\bar{h}_e = 0.9\,Ar^{0.1}\Theta^{0.71}. \tag{2}$$

It is valid in the range of values $0.06 \le Ar \le 0.36$; $3.28 \le \Theta \le 4.37$; $1.18 \le d_0/d \le 2.16$; $1.7 \cdot 10^{-4} \le \rho''/\rho' \le 2.13 \cdot 10^{-4}$. The density of the combustion products ρ'' is selected according to their temperature at the exit from the burner T'', and the density of the liquid ρ' by means of the temperature of the liquid in the apparatus T'. The velocity of the burning combustion products at the exit from the burner is part of the complex Ar. Equations for the depth of burner submersion in the apparatus with a bubble grating

$$\bar{h}_e = 0.76\,Ar^{0.1}\Theta^{0.71} \tag{3}$$

and with a circulation tube

$$\bar{h}_e = 0.72\,Ar^{0.1}\Theta^{0.71}\left(\frac{d_E}{d}\right)^{0.15}. \tag{4}$$

were found analogously. By using the equations of material and heat balance of the apparatus, the thermal productivity of the burner could be found, and, hence, the consumption of the fuel delivered to the burner. Furthermore, by using the usual method of computing energetic burner units, the consumption of the fuming gases, their temperature, and the inner diameter of the burner can be determined. This permits computation of the values of the numbers Ar and Θ and the equilibrium depth of burner submersion at which the most complete utilization of the heat of the burning fuel in the ASB is assured, by means of (2), (3), or (4).

NOTATION

h, depth of burner submersion; T, t, temperatures; ρ, density; W, velocity; d, d_0, burner inner and outer diameters; d_E, equivalent diameter of the circulation tube channel. The superscript " refers to the gas and ' to the liquid; $Ar = (W'')^2\rho''/gd(\rho' - \rho'')$ is a modification of the Archimedes number, while $\Theta = T''/T'$ is a temperature factor and l is a linear dimension.

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