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MATHEMATICAL MODEL OF CONTACT HEAT EXCHANGE OF A GAS AND WATER DURING ADIABATIC EVAPORATION

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It is shown that the gas temperature distribution in a contact heat exchanger is characterized by the presence of two zones during adiabatic evaporation — an initial zone with a reduced temperature and a final zone with an elevated temperature — as compared with the heat exchange through a separating surface.

Heat exchange with direct contact between the high-temperature gas and water is used in different industrial apparatus (moistening columns, scrubbers of "wet" gas cleansers). In all these cases, adiabatic evaporation of the water is observed.

To estimate the modes of operation of technological equipment it is necessary to know the nature of the heat-carrier temperature distribution along the heat exchange surface. The temperature distribution in a contact heat exchanger differs from that which holds in ordinary heat exchangers with separating surfaces which, as is known, is described sufficiently accurately by a logarithmic curve [1, 2].

To find the nature of the change in gas temperature during adiabatic evaporation, we use the fundamental heat exchange equation

$$G_g(c_g + c_v x)\,dt = \alpha(t - t_f)\,dF + dG\,(c_{v1}t - c_{v2}t_f). \tag{1}$$

This relationship has two distinctions from the ordinary heat exchange equation through a separating surface: 1) the second term on the right side takes account of the additional expenditure of heat on reheating the connecting couple from the fluid temperature to the gas temperature; 2) during heat exchange the moisture content of the gases, their mass and the mass specific heat $(c_g + c_v x)$ vary.

If we find

$$dG = \frac{\alpha(t - t_f)\,dF}{r}, \tag{2}$$

determine x from the expression $\alpha(t - t_f) = \beta r(x'' - x)$,

$$x = x'' - \frac{\alpha}{\beta r}(t - t_f), \tag{3}$$

substitute (2) and (3) into (1), and take into account that

$$c_g = c_{gf} + \Delta_c(t - t_f) \text{ and } c_v = c_{vf} + \Delta_m(t - t_f),$$

then after manipulation we obtain

$$\left(\frac{C_1}{t_1 - t_f} - \frac{C_2}{t^2 + bt + C} - \frac{C_3 t}{t^2 + bt + C}\right)dt = dF.$$

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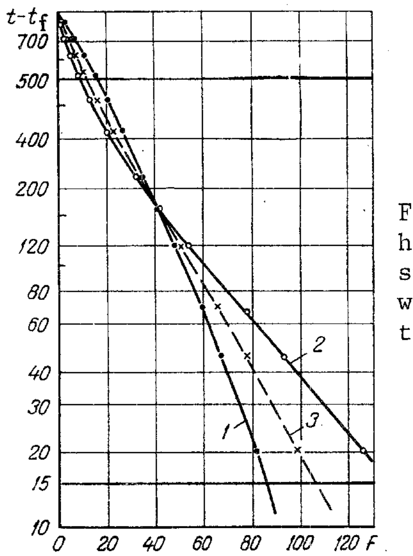

Fig. 1. Change in gas temperature during heat exchange: 1) through the separating surface; 2) for adiabatic evaporation with α = const; 3) the same, for α = var. $t - t_f$, °K; F, m^2.

After integration between the limits t_1 and t_2, we have a solution in the form

$$F_{1-2} = C_1 \ln \frac{t_1 - t_f}{t_2 - t_f} - C_4 \ln \frac{t_1^2 + bt_1 + C}{t_2^2 + bt_2 + C} + C_5 [\operatorname{arc\,tg}(C_6 t_1 + C_7) - \operatorname{arc\,tg}(C_6 t_2 + C_7)], \tag{4}$$

where C_1, C_2, C_3, C_4, C_5, C_6, C_7 are coefficients determined by the thermophysical, aerodynamic characteristics of the process independent of the gas temperature.

It was assumed in the derivation that α = const. The results of solving (4) and the classical equation for heat exchange through a separating wall (taking account of the change in the specific heat of the dry gas from the temperature) are compared in Fig. 1 in graphical form. Computations were performed for the following conditions: t_1 = 1273°K, G_g = 1500 kg/h, α = 83.8 kJ/m^2·°K, c_{gf} = 1.007 kJ/kg·°K, c_{vf} = 2.038 kJ/kg·°K, t_f = 356°K, x" = 0.71 kg/kg.

As is seen the temperature distribution of the gas during heat exchange through a surface in semilogarithmic coordinates is almost rectilinear. At the same time, the temperature distribution during adiabatic evaporation deviates substantially from the rectilinear and is expressed by a curve characterized by two domains. In the first stage, the vapor adjoining the gas causes a significant expenditure of heat to heat it to high temperature and, consequently, additional cooling of the gas. Later the increase in the mass consumption of the vapor—gas mixture starts to be felt; the cooling is retarded and the mixture temperature in the second stage of the process is substantially higher than during cooling of the dry gas.

However, it should be noted that the described regularity is observed under the assumption that the magnitude of the heat exchange coefficient α is constant throughout the process. Values of α vary substantially in real heat exchangers because of a number of factors. Firstly, this is determined by the diminution in the volume and velocity of the gases due to the reduction in their temperature. In a first approximation, the change in α because of the temperature factor during heat exchange through a surface and during adiabatic evaporation can be considered identical. The additional singularity of contact heat exchange is that an increase in the mass of the vapor—gas mixture exerts a secondary influence because of evaporation: on the one hand, the temperature reduction is retarded because of the increase in the bulk specific heat of the mixture, while, on the other hand, the volume, velocity, and, therefore, the quantity α increase. Usually the change in α due to the gas velocity is described by a dependence of the kind $\alpha = W^n$, where n = 0.5, ..., 0.8.

The increase in α due to the gas velocity increment because of the increase in its mass can be taken into account by the introduction of a correction factor in the formula for α: $\alpha = \alpha_0 [1 + x(\rho_g/\rho_v)]^n$, which takes on the form

$$\alpha = \alpha_0 [M - N(t - t_f)]^n \tag{5}$$

in the expression of x as a function of the running temperature difference. Taking n = 0.5 and substituting the value of α from (5) into (4), a solution can be obtained in which the change in the heat exchange coefficient is taken into account because of the increase in the gas volume and velocity. The integral obtained here has no exact analytic solution and is determined by numerical methods. Also superposed on Fig. 1 is a curve which is the solution of the equation obtained with the variability of α taken into account. As is seen, taking account of the variability of α substantially smooths the nature of the dependence in the second stage of the process by approximating it to that available during heat exchange through a surface.

Therefore, the change in gas temperature during adiabatic evaporation is characterized by two zones: the temperature is reduced more abruptly compared to the case of heat exchange through a surface in the first stage, while, on the other hand, the gas temperature is raised during evaporation in the second stage.

NOTATION

α, β, heat and mass exchange coefficients; t, t_f, gas and fluid temperatures; x, x_f, moisture content of the gas and saturation at t_f; c_{gf}, c_{vf}, specific heats of the dry gas and the vapor at t_f''; G_g, G_v, gas and vapor consumptions; F, heat exchange surface; r, latent heat of vapor formation; $\Delta_c = (c_g - c_{gf})/(t - t_f)$, $\Delta_m = (c_v - c_{vf})/(t - t_f)$, temperature coefficients of the specific heat.

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HEATING CHARACTERISTIC OF IMPERFECT DIELECTRICS IN A TRAVELING ELECTROMAGNETIC WAVE FIELD

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A new characteristic of a dielectric in an electromagnetic field, the rate of adiabatic heating of the boundary of a semiinfinite dielectric bulk under normal incidence by an electromagnetic wave, is proposed to describe the heating of dielectrics whose parameters are temperature dependent.

At this time, heating of dielectrics in a traveling electromagnetic microwave field is used more and more often in addition to the traditional method of heating imperfect dielectrics in the field of a high-frequency capacitor in order to change some physical or chemical characteristics of the material.

Performing the experiments and producing the appropriate apparatus required a preliminary estimation of the rate of dielectric heating. As a rule, the tangent of the dielectric loss angle ($\tan\delta$) or the loss factor ($\varepsilon'' = \varepsilon'\tan\delta$) is used as the main characteristic of the influence of the electromagnetic field on the dielectric. Meanwhile it is still impossible to determine the rate of dielectric heating in an electormagnetic field by means of these quantities. The fact is that the electrical and thermophysical characteristics depend on the temperature for the majority of the materials and therefore they vary during action. This latter results in the appearance of a number of competing processes during the heating, which makes estimationof the magnitude of the heating rate difficult. Thus, for instance, ε', $\tan\delta$, and the specific heat c grow during heating in a number of materials. The increase in ε' and $\tan\delta$ results in a diminution in the depth of electromagnetic field penetration h into the material and an increase in the heating rate of the dielectric layer adjacent to the air–dielectric interface. On the other hand, as ε' increases, the coefficient of reflection from this boundary increases, i.e., the quantity of electro-

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