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SUBLIMATION IN A FLAT CHANNEL WITH A MOVABLE WALL AND A PERMEABLE WALL

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The effect on the process of heat exchange in a narrow slotted channel of an asymmetrical suction of subliming vapor through a permeable wall in the presence of a parallel movable wall has been examined.

In [1], the one-dimensional problem for Couette flow has been solved and tested experimentally. In [2], the mechanism of heat- and mass-transfer in the sublimation process in flat channels is studied. In the present work, the process of heat exchange in a slotted channel when the subliming vapor is sucked through the heat-generating wall is examined under assumption [3].

Consider a steady process of heat- and mass-exchange in a flat slotted channel of height H (Fig. 1). We assume that the upper subliming wall moves in its plane with the constant velocity U*. The vapor, subliming in the channel with the velocity v_W of the upper movable wall, is sucked out with velocity v_0 through the lower wall, affected by the outer heat flow of intensity q. In this case, the flow of vapor can be described in the dimensionless form by the Navier—Stokes equations in combination with the continuity equation and boundary conditions

$$(\mathbf{v}\cdot\nabla)\,\mathbf{v} = -\nabla p + \frac{1}{\mathrm{Re}}\,\Delta\mathbf{v}, \tag{1}$$

$$\nabla\cdot\mathbf{v} = 0, \tag{2}$$

$$u(0) = 0,\ v(0) = \beta,\ u(1) = \frac{U^*}{v_c},\ v(1) = 1, \tag{3}$$

where $\beta = v_0/v_W$ is the dimensionless coefficient of suction of the subliming vapor ($0 \leqslant \beta \leqslant 1$).

We seek a solution of system (1), (2) with the boundary conditions (3) as in [2].

$$u = -xf'(y),\ v = f(y). \tag{4}$$

In this case, Eq. (2) is an identity, while Eq. (1) and conditions (3) take the form

$$f'^2 - ff'' + \frac{1}{\mathrm{Re}}\,f''' = -\frac{1}{x}\,\frac{\partial p}{\partial x}, \tag{5}$$

$$ff' - \frac{1}{\mathrm{Re}}\,f'' = -\frac{\partial p}{\partial y},$$

$$f'(0) = 0,\ f(0) = \beta,\ f'(1) = U,\ f(1) = 1, \tag{6}$$

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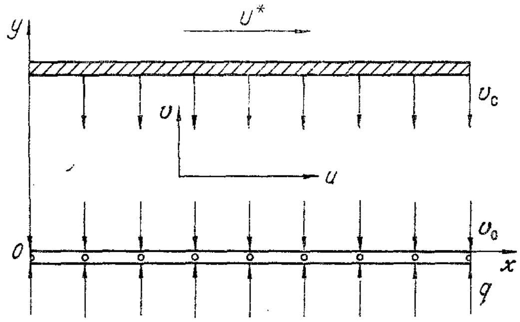

Fig. 1. Diagram of the flow region in a flat channel.

where $U = -U^*/xv_W$ is a dimensionless complex, characterizing the velocity of displacement of the upper wall.

Following [3], instead of (5), we find

$$f''' + \mathrm{Re}(f'^2 - ff'') = k = \mathrm{const}. \tag{7}$$

By using the method of successive approximations and assuming that $\mathrm{Re} \ll 1$, we obtain the solution of (7) by virtue of two approximations

$$f = ay^2 - by^3 + \beta + \left[\frac{y^2}{10}\left(ab - \frac{2a^2}{3} - \frac{4b^2}{7} - \frac{5b\beta}{2}\right) + \right.$$
$$\left. + \frac{y^3}{6}\left(\frac{3a^2}{5} - \frac{4ab}{5} + \frac{3b^2}{7} + 3b\beta\right) - b\beta y^4 - \frac{a^2}{30}y^5 + \frac{ab}{30}y^6 - \frac{b^2}{70}y^7\right]\mathrm{Re} + \ldots,$$

$$k = -6b + \left(\frac{3a^2}{5} - \frac{4ab}{5} - 2a\beta + \frac{3b^2}{7} + 3b\beta\right)\mathrm{Re} + \ldots,$$

where $a = 3(1 - \beta) - U$, $b = 2(1 - \beta) - U$.

Now, taking account of (8), the dependencies (4), which determine the field of velocities in the flat channel, are reduced to the form

$$u = -x\left[2ay - 3by + \left(\frac{A}{5}y + \frac{B}{2}y^2 - b\beta y^3 - \right.\right.$$
$$\left.\left. - \frac{a^2}{6}y^4 + \frac{ab}{5}y^5 - \frac{b^2}{10}y^6\right)\mathrm{Re} + \ldots\right], \tag{9}$$

$$v = ay^2 - by^3 + \left(\frac{A}{10}y^2 + \frac{B}{6}y^3 - \frac{b\beta}{4}y^4 - \frac{a^2}{30}y^5 + \frac{ab}{30}y^6 - \frac{b^2}{70}y^7\right)\mathrm{Re} + \ldots, \tag{10}$$

where

$$A = ab - \frac{2a^2}{3} - \frac{4b^2}{7} - \frac{5b\beta}{2}; \quad B = \frac{3a^2}{5} - \frac{4ab}{5} + 3b\beta.$$

We now turn our attention to the analysis of the process of heat transfer in the channel. For the case in question, the equation of heat conduction and the boundary conditions are of the form

$$\frac{d^2T}{dy^2} = v\,\mathrm{Pe}\,\frac{dT}{dy}, \tag{11}$$

$$T(1) = 1, \quad \frac{dT}{dy}(1) = -m. \tag{12}$$

Taking account of [3], the solution of Eq. (11), which enables us to obtain temperature distribution along the channel's height, with allowance for (12) and the function (10), can be written in the form

$$T(y) = 1 - m\left\{ y - 1 + \mathrm{Pe}\left[\frac{a}{12}(y^4 - 1) - \right.\right.$$

$$\left.\left. - \frac{b}{20}(y^5 - 1) + \frac{\beta}{2}(y^2 - 1) - \left(\frac{a}{3} - \frac{b}{4} + \beta \right)(y - 1) \right]\right\}. \tag{13}$$

Consider also solution (11) under the assumption that the temperature on the surfaces of the lower and upper walls of the channel is constant:

$$T(0) = \tau,\ T(1) = 1, \tag{14}$$

where $\tau = T_0^*/T_c$. As a result we obtain

$$T(y) = (1 - \tau)\frac{\int\limits_0^y \left[\exp\left(\mathrm{Pe}\int\limits_0^y v\,dy\right)\right] dy}{\int\limits_0^1 \left[\exp\left(\mathrm{Pe}\int\limits_0^y v\,dy\right)\right] dy} + \tau.$$

Now, using relationship (10) and taking account of (14), we obtain

$$T(y) = (1 - \tau)\left\{ y + \left[\frac{a}{12} y^4 - \frac{b}{20} y^5 + \frac{\beta}{2} y^2 - \left(\frac{a}{12} - \frac{b}{20} + \frac{\beta}{20} \right) y \right] \mathrm{Pe} \right\} + \tau. \tag{15}$$

We estimate the intensity of heat exchange on the surface of the permeable wall with the help of the Nusselt criterion

$$\mathrm{Nu}(0) = \frac{\frac{dT}{dy}(0)}{T(1) - T(0)}. \tag{16}$$

It is not difficult to see that for each particular case the use of (13) or (15) leads to the identity

$$\mathrm{Nu}(0) = 1 - \left(\frac{a}{12} - \frac{b}{20} + \frac{\beta}{2} \right) \mathrm{Pe}. \tag{17}$$

After performing simple transformations, we obtain

$$\mathrm{Nu}(0) = 1 - \left(\frac{3}{20} - \frac{U}{30} + \frac{7}{20}\beta \right) \mathrm{Pe} \tag{18}$$

instead of (17).

From (18), it follows that the Nusselt numbers decrease as the values of Pe, U, and β increase. At the same time, the largest values of the coefficient of suction of subliming vapor correspond to the reduction in the intensity of heat exchange on the heat-generating surface during evaporational cooling in the process of sublimation. Apparently, specific limitations can be imposed on the velocity of motion of the movable wall and, therefore, on the Peclet numbers. These circumstances indicate a positive role of the enumerated factors in the problems of heat protection.

NOTATION

$x = x^*/H$, $y = y^*/H$, dimensionless physical coordinates; $\mathbf{v} = \{v, u\}$, velocity vector; $\mathrm{Re} = Hv_c/\nu$, Reynolds number; ν, kinematic viscosity coefficient; ∇, ∇, Δ, differential gradient, divergence, and Laplace operators, respectively; $v = v^*/v_c$, $u = u^*/v_c$, dimensionless transverse and longtudinal velocity components; $p=p^*/\rho v_c$, dimensionless pressure; ρ, gas density; Pe, Peclet number; λ, thermal conductivity; c_p, heat capacity at constant pressure; $m=\mathrm{Pe}r_c/T_c c_p$, dimensionless complex; $r_c=q/\rho v_c$, heat of sublimation; T_c, sublimation surface temperature; $T=T^*/T_c$, dimensionless temperature; T_0, lower wall surface temperature; $\mathrm{Nu}=H/\rho c_p$, Nusselt number.

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ROLE OF DROP SUPERHEATING IN THE NONSTEADY DROP COOLING OF A HIGH-TEMPERATURE WALL

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The influence of superheating and explosive boiling of a contact layer of drops on the heat transfer in drop cooling of a wall at a temperature exceeding the temperature of achievable heating of the liquid is considered.

Investigations of the interaction between a drop and a hot surface have mainly related to a large drop present on a horizontal surface for a relatively long time (a spheroidal state of the drop) [1]. In these conditions, the interaction process between the drop and the surface is steady, and the basic mechanism of heat transfer from the surface to the drop is heat transfer through a steady vapor layer. However, with short-term impact of the drop on the wall surface, no steady vapor layer is able to develop, and therefore its role may be insignificant. In the latter case, drop contact with the surface that is close to "liquid contact" may be realized. Then the heat conduction in the drop itself plays the basic role in the heat-transfer process. With sufficiently brief contact, impulse heating of the contact layer of the drop occurs; this leads to superheating and explosive effervescence of this layer. After effervescence, the wall layer becomes a finely disperse two-phase system, and then a vapor. At this stage, the intensive induced convection in the layer excited by explosive boiling plays an important role in heat transfer.

This nonsteady heat-transfer mechanism occurs in the initial stage of any contact between liquid and high-temperature solids. However, if the overall contact time is much larger than the time of heating and explosive boiling of the contact layer, the role of this mechanism is slight in comparison with the steady mechanism of heat transfer through the steady vapor layer. In the case of short-term contact, however, the nonsteady mechanism may play the fundamental role in heat transfer from a heated wall. If such conditions arise in the course of drop cooling, considerable increase in heat transfer in comparison with the heat transfer in steady conditions through the vapor layer may be expected on account of the above-noted intense heat-transfer mechanisms.

In describing drop cooling, no account is usually taken of drop superheating and the explosive boiling of the contact layer [1]. The aim of the present work is to rectify that omission to some degree.

1. Temperature and Time of Achievable Superheating of Liquid

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