THEORETICAL INVESTIGATION OF LAMINAR FILM CONDENSATION OF A SATURATED VAPOR FLOW OVER AN ISOTHERMAL SURFACE

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Inzhenerno-Fizicheskii Zhurnal, Vol. 15, No. 3, pp. 537–539, 1968

UDC 532.517.2

Numerical solutions are obtained for the system differential equations describing the process of condensation of a saturated vapor flowing over an isothermal surface.

In [1] Koh solved the problem of calculating the stationary process of film condensation of a saturated vapor moving at constant velocity along an isothermal flat plate whose temperature is less than the saturated vapor temperature (Fig. 1). It was assumed that gravitational forces were absent and that the condensate film is entrained in the direction of motion of the flow only by the forces of friction between the film and the vapor. It was further assumed that the motion in the external vapor flow, in the vapor boundary layer and in the condensate film is laminar, that waves are not formed on the surface of the film and that the physical parameters of the condensing vapor do not depend on temperature. By means of a change of variables the starting system of partial differential equations, describing the flow in the condensate film and the vapor boundary layer, was reduced to a system of ordinary differential equations and solved on a computer for a broad variation of the parameters.

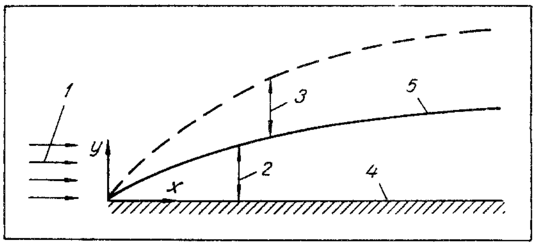

Fig. 1. Physical model of the problem: 1) saturated vapor flow; 2) condensate film; 3) boundary layer; 4) isothermal surface; 5) condensate-vapor interface.

It is possible to solve the analogous problem for the more general case when the velocity of the external flow can be specified in the form of a power monomial $U(x) = cx^m$, where c and m are certain arbitrary constants (m is dimensionless). At m greater and less than zero we have accelerating and decelerating flows, respectively.

In this case, it must also be assumed that the density and temperature of the vapor are constant on the section in question and equal to their averaged values for that section.

Then the starting system of equations will differ from that considered in [1] only with respect to the presence in the equations of mechanics for the film and the vapor layer of terms that take into account the variation of pressure along the plate. This system of equations is reduced to a system of equations in total derivatives in the same way as in [1]. However, in this case, together with the parameters R, $\eta_{\delta l}$ and Pr obtained in [1], there appear the two new parameters m and $\xi = \rho_v/\rho_l$.

Certain results of a numerical computer solution of this system by the same method as employed in [1] are presented in Fig. 2, from which it is clear, in particular, that the characteristics of the condensation process depend very strongly on the parameter m, characterizing the pressure gradient along the condensation boundary.

In conclusion, the authors thank I. P. Karpenko for assisting with the numerical calculations.

NOTATION

$U(x) = cx^m$—free-stream vapor flow velocity (c and m are dimensional and dimensionless arbitrary constants,

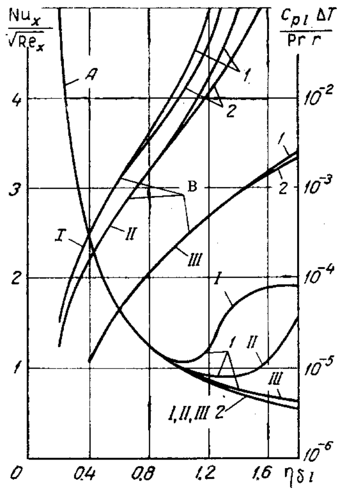

Fig. 2. The complexes $Nu_x\sqrt{Re_x}$ (A) and $c_{pl}\Delta T/Pr\ r$ (B) as functions of $\eta_{\delta l}$ at $\xi = 10^{-3}$ and R = 316 (μ_l/μ_v = 100) for various values of the parameters m and Pr: I) m = 2; II) m = 1; III) m = 0.02; 1) Pr = 100; 2) Pr = $3 \cdot 10^{-3}$.

respectively)
ρ—density
ν and μ—kinematic and dynamic coefficients of viscosity, respectively;
T—temperature
λ—thermal conductivity
c_p—specific heat at constant pressure
ΔT—difference of temperatures of saturated vapor T_v and isothermal surface T_p
$\eta_{\delta l} = \delta\sqrt{cx^m/\nu_l}$ —dimensionless coordinate of phase interface
δ—thickness of the condensate film
$Re_x = cx^{m+1}/\nu_l$ —Reynolds number
$Nu_x = x\left(\frac{\partial T}{\partial y}\right)_{y=0} \Big/ \Delta T$—Nusselt number
$Pr = c_{pl}\mu_l/\lambda_l$ —Prandtl number
$\xi = \rho_v/\rho_l$
$R = (\rho_l\mu_l/\rho_v\mu_v)^{1/2}$
r—latent heat of evaporation
Subscripts: l—liquid, v—vapor.

REFERENCE

1. J. C. I. Koh, Int. J. Heat and Mass Transfer, **5**, October, 1962

15 January 1968