
NONSTEADY FILTRATION OF SATURATED WATER
VAPOR IN DISPERSE MEDIUM

V. L. Ganzha and G. I. Zhuravskii

Analytic relations are obtained for the calculation of the temperature and pressure distribution in a disperse medium, and also the depth of the heated region in the filtration of saturated water vapor.

Questions associated with the investigation of saturated-water-vapor filtration in disperse media is of particular urgency at present in connection with the prospect of making effective use of the method of vapor-heat treatment as a means of increasing the petroleum yield of a bed. The main aim of the investigation, of course, is to obtain analytical relations allowing the vapor parameters in the course of filtration and its penetration depth in the plate to be obtained.

In most works devoted to the solution of this problem (e.g., [1-4]), integrodifferential heat-balance equations are used. However, in ignoring the hydrodynamics of the process, this approach can obviously only give satisfactory approximation in thermal calculations for very small $\Delta T$, since it is assumed, in the absence of information on the form of the pressure or temperature distribution, that $\Delta T = \text{const}$.

In [5-8], an attempt was made to use relations obtained on the basis of a system of differential equations [9]. However, these equations were derived for the drying of capillary-porous bodies, and cannot be applied outside the scope of problems of diffusional-filtration transfer at small pressure gradients.

The physical picture of the problem is reflected more completely and accurately in [10], where a system of equations of nonisothermal multicomponent filtration is given. However, its use involves serious mathematical difficulties, and moreover mathematical inaccuracy was assumed in deriving the energy equation of the multicomponent flux.

Thus, as far as is known, relations for the calculation of saturated-vapor filtration in a disperse medium which are both sufficiently well-founded and expedient for use are not to be found in the literature at present.
Fig. 1. Comparison of calculated (curves 1-4) and experimental data on the pressure distribution over the layer height at the phase transition boundary, \( x = H; H = 2.5 \) (1), 7.5 (2), 12.5 (3), and 17.5 (4) cm. \( P \times 10^5, \text{N/m}^2; x \times 10^{-2} \text{m}. \)

In the deriving analytical relations determining the form of the pressure and temperature distribution in a disperse medium, and also the depth of the heated zone in the filtration of saturated water vapor, a number of assumptions made in earlier experimental work [11] will be adopted. In particular, it is assumed that the compensation process is limited not by heat and mass transfer but by the rate at which vapor reaches the condensation region; that the main flux of phase-transition material is concentrated in a narrow zone at the boundary between the moist (saturated condensate) and dry regions of the disperse medium; that the pressure in the liquid condensate film and the vapor phase is the same; and that vapor filtration behind the condensation front occurs in accordance with Darcy's law.

In considering filtration, the method of steady-state succession is used [12]; in this method, nonsteady filtration is treated as a set of instantaneous steady processes with characteristics continuously changing over time. The Clapeyron--Clausius equation is taken as the relation between the change in pressure at the saturation line and the change in temperature. First, consider the case of linear filtration of water vapor as an ideal gas.

The given problem may be formulated mathematically as follows

\[
\frac{dP}{dT} = \frac{r}{T \Delta V}, \quad \rho = \frac{P \mu}{RT}, \quad \rho \frac{dP}{dx} = -\frac{\eta}{k_v} j_v
\]

with the boundary condition

\[
T_{x=H} = T_0, \quad P_{x=H} = P_0.
\]

The solution of Eq. (1) may be written in the form

\[
\frac{P_{x}}{2} \ln C_1 - \left( \frac{P_{x}}{2} \ln P - \frac{P_{x}^2}{4} + C_2 \right) = -\frac{\eta}{k_v} j_v x
\]

or

\[
\frac{P_{x}^2}{2} \left( \ln \frac{C_1}{P} + \frac{1}{2} \right) = C_2 - \frac{\eta}{k_v} j_v x,
\]

where \( C_1 \) and \( C_2 \) are constants of integration

\[
C_1 = P_0 \exp \left( \frac{\mu_r}{RT_v} \right); \quad C_2 = \frac{P_0^2}{2} \frac{\mu_r}{RT_v} + \frac{P_0^2}{4} + \frac{\eta}{k_v} j_v H.
\]

The expression for determining the temperature distribution is then