


INVESTIGATION OF THE HYDRODYNAMIC REGIMES OF A LIQUID IN A SMOOTH-WALLED ROTATING HEAT PIPE. II

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The article deals with the analytical and experimental investigation of the influence of the slope of a rotating heat pipe and of the taper of its inner surface on the hydrodynamics of a liquid.

The heat transfer ability and other characteristics of a rotating heat pipe (RHP) depend largely on the orientation in the gravity field, which is particularly noticeable at relatively low rotational speeds, and on the geometry of the inner surface.

Let us examine the operation of a RHP in the range of slopes of the axis $0 < \beta < \beta_d$, where $\beta_d$ is the maximum angle at which the axial component of the centrifugal force cannot ensure transport of the heat carrier from the zone of condensation to the zone of evaporation, i.e., the extreme section of the zone of heat supply begins to dry.

When $\beta > 0$ and the rotational speed $\omega$ is low, the liquid is redistributed along the $x$ axis in the groove. If $\omega$ is sufficiently large for the liquid to spread over the inner surface without forming a groove, then the redistribution is determined by the ratio of the axial component of the force of gravity to the pressure gradient $\Delta p$ in the liquid layer formed on account of the longitudinal thickness gradient $\delta_x$. In either case the mean thickness of the layer over the perimeter $\delta_x = \delta_x/2\pi R$ is a function of the coordinate $x$. When $\beta = 0$ or $\omega = \omega$, $\delta_x = \delta = \text{const}$. When $\beta > 0$, the number $Re_x = \omega (\delta_x)^2/\nu$, determining, together with the number $Fr_c = \omega^3 R/\mu$, the flow regime (see Fig. 1 [1]), is also a function of $x$ as distinct from the horizontal position of the pipe at which the Reynolds number is constant for a specified value of $\omega$.

Thus, when a RHP is inclined, the Reynolds number along the pipe changes, and in consequence a complex hydrodynamic pattern arises in it; this pattern is characterized by the simultaneous existence of different flow regimes described in [1].

We obtain the dependence of $\delta_x$ on the coordinate $x$ for two characteristic cases: a) for small values of $\omega$ at which there is a groove in the lower part of the pipe; b) for high speeds when the liquid spreads over the entire inner surface.

Taking small values of the angle $\beta$, and consequently a very slight longitudinal component of the force of gravity, we assume that with small $\omega$ the dependence of $\delta_x$ on $x$ with specified amount of liquid and specified geometry of the pipe is determined solely by the slope. This assumption means that in the range of rotational speeds at which there exists a groove, the liquid moves in a plane perpendicular to the longitudinal axis of the pipe, and does not move axially.

The expression for the volume of liquid in a pipe with $\beta > 0$ has the form (Fig. 1):

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When the pipe is situated horizontally ($\beta = 0$), the volume of liquid in it is determined by the equation

$$V = SI = \frac{R^2}{2}\left(2\varphi_3^5 - \sin 2\varphi_3^5\right). \tag{2}$$

To simplify Eqs. (1) and (2), bearing in mind that the angles $\varphi_{30}, \varphi_{31}, \varphi_3^5$ do not exceed $\pi/4$, it suffices to replace the trigonometric functions by two terms of their Taylor expansion. However, such substitution in (1) has the effect that the terms in parentheses on its right-hand side cancel each other. Therefore, if we confine ourselves to three terms of the series in Eq. (1) and to two terms in Eq. (2), and if we equate their right-hand sides and carry out the corresponding transformations, we obtain

$$\left(\varphi_3^0\right)^3 = \frac{R}{5\tan \beta} \left(\varphi_{30}^5 - \varphi_{31}^5\right). \tag{3}$$

From (2) we have

$$\varphi_3^0 = \sqrt[3]{\frac{3V}{2IR^2}} = \sqrt[3]{3\pi \Delta}. \tag{4}$$

We express $\varphi_{3x}$ (the angle in an arbitrary section $x$) through $\varphi_{30}$:

$$\varphi_{3x} = \arccos \left(\cos \varphi_{30} + \frac{x}{R} \tan \beta\right). \tag{5}$$

If we substitute $\varphi_{3x}$ from Eq. (5), with $x = 1$, into (3), we obtain

$$\left(\varphi_{30}^0\right)^3 = \frac{1}{5\tan \beta} \left[\varphi_{30}^5 - \arccos^5 \left(\cos \varphi_{30} + p \tan \beta\right)\right]. \tag{6}$$

The numerical solution of the transcendental equation (6) with respect to $\varphi_{30}$ in the range of change $\beta = 0^\circ - 4^\circ$, $p = 6 - 24$, $\varphi_3^5 = 0 - \pi/4$ is approximated with an accuracy of 2% by the expression

$$\varphi_{30} = \sqrt[3]{3\pi \Delta} + 9.44 \times 10^{-2} \left(\frac{p^{1.3}}{\Delta^{0.32}}\right)^{0.62} \beta^{0.87}. \tag{7}$$

Using Eq. (4), we determine the value of $\delta_x$:

$$\delta_x = \frac{S_x}{2\pi R} = \frac{(\varphi_{3x})^R R}{3\pi}. \tag{8}$$