The film condensation of vapor on a horizontal tube with trapezoidal fins is calculated analytically for the case where surface tension is predominant. Experimental results for water and Freon-113 vapors are also shown.

The article deals with an analytical and an experimental study of heat transfer during film condensation of a stationary vapor on horizontal tubes with circumferential trapezoidally shaped fins (Fig. 1a, b), under conditions where the effect of surface tension is predominant. As has been mentioned in [7, 8], it is possible with such a finning to considerably enhance — as compared with smooth tubes — the process of heat transfer from vapor to tube wall.

Such a finning would probably be most effective on the surface of a horizontal tube, where surface tension will constrict the liquid condensing on the fins — around the entire tube circumference — into the drains (recesses between fins). At the same time, the fin crests (overhangs) become cleared of liquid and vapor condensation will occur primarily there. One can realize such a pattern of condensate film flow by properly designing the dimensions of the basic fin elements so that the surface tension at the crest surface will be greater than the force of gravity by at least one order of magnitude, i.e., so that $We > 10$.

The Weber number, which is the ratio of these two forces, can be expressed as follows:

$$We = \frac{\sigma \cos \varphi}{\rho b (1 + \tan \varphi)}$$

where the pressure gradient $\frac{\partial p}{\partial x}$ at a certain depth of fin immersion $\Delta$ (Fig. 1) may be expressed as

$$\frac{\partial p}{\partial x} \approx \frac{\Delta p}{\Delta x} \approx \frac{\sigma \cos \varphi}{R_y (b - \Delta)}$$

and the radius of the liquid film curvature $R_T$ at the top of a trapezoidal fin can be determined, to a first approximation, by the formula:

$$R_T = b (1 + \tan \varphi).$$

It is evident from (1) that by decreasing $b$ and angle $\varphi$, with given physical properties ($\sigma$, $\rho$) of the substance, one can always attain the condition at which $We \geq 10$.

While observing the basic requirement $We \geq 10$, we will analyze the motion of a condensate film along a horizontal tube with circumferential fins under the following assumptions:

1. The thin condensate film on the overhang will be treated as a laminar boundary layer, with the pressure gradient along the profile determined by the prevalent surface tension. The effect of gravity and
forces on the motion of the film along the lateral surface of a fin toward the bottom will be dis-
regarded.

2. The motion of the condensate into the drain is laminar and occurs due to gravity. Vapor con-
densation directly at the bottom is not taken into account, because the film is very thick here.

3. The wall temperature will be assumed constant across the height of the fin.

Starting out with the basic assumptions concerning the mechanism of heat transfer through a liquid
film, which were introduced by Nusselt [6] in an analysis of vapor condensation on smooth surfaces, and
solving the differential equation of condensate flow along the fin into the drain (Fig. 1b)
\[
\frac{1}{\mu} \frac{\partial p}{\partial x} + \frac{\partial W_y}{\partial y} = 0
\]
with the boundary conditions \( W_y = 0 \) at \( y = 0 \) and \( \frac{\partial W_y}{\partial y} = 0 \) at \( y = \delta \), we find the mean film velocity over
the fin height
\[
\bar{W}_y = \frac{\delta^2}{3\mu} \frac{\partial p}{\partial x} = \frac{\delta^2 \cos \psi}{3(h - \Delta)(1 + \tan \psi) \beta \mu}
\]
and the thickness of the condensate film on the fin
\[
\delta = \left( \frac{4\mu \lambda (1 - \tan \psi)(h - \Delta) \beta \mu}{\rho \sigma \cos \psi} \right)^{1/4}
\]
as functions of the physical properties of the condensing liquid, of the fin dimensions, and of the yet un-
known liquid height.

This part of the analysis has been presented more completely in [3].

In order to calculate the motion of a liquid layer \( \Delta \) along a trapezoidal channel between fins under the
action of gravity, we need some additional assumptions:

1. The motion of the liquid is laminar with respect to the lateral fin surface immersed in the layer
\( \Delta \). The effect of the tube wall section (base \( a \)) is disregarded.

2. Within the immersion zone, along the \( y \)-coordinate from the fin wall to the groove axis the velocity
distribution is considered semiparabolic; according to Nusselt, for a two-dimensional flow of a
liquid film under the action gravity:
\[
U_y = \frac{\rho \sin \psi}{\mu} \left( \delta_{det} y - \frac{y^2}{2} \right),
\]
where
\[
\delta_{det} = (a + \Delta \tan \psi).
\]

Fig. 2. Relative height of liquid around the tube, for \( H = 0.03 \)
and different values of the parameter \( m \).

Fig. 3. Height of liquid at the boundary with the drip region
of a tube (at \( \psi = 150^\circ \)), for different values of parameters \( H \)
and \( m \): 1) \( H = 0.30 \); 2) 0.20; 3) 0.07; 4) 0.05; 5) 0.03; 6) 0.02;
7) 0.01; 8) 0.005; 8) 0.0025; 10) 0.001; 11) 0.0005.