MINIMUM IRRIGATION DENSITY OF VERTICAL FILM APPARATUS

E. G. Vorontsov

Inzhenerno-Fizicheskii Zhurnal, Vol. 14, No. 6, pp. 1075–1078, 1968

UDC 66.05.001.5

The minimum irrigation density of a film heat exchanger is studied in relation to the temperature regime, the roughness of the wall surface, its material, and certain structural features of the distributor.

One of the principal characteristics of film heat exchangers is the "minimum irrigation density," since the heat transfer from the wall to the liquid film depends not only on the flow regime but also on the wetting conditions at the heat-transfer surface [3]. The minimum irrigation density Γ_{min} is usually defined as the least amount of running liquid required to completely wet the surface per unit wetted perimeter per unit time.

At irrigation densities less than Γ_{min} the nature of the film flow changes; as a result of incomplete wetting, the heat-transfer surface is only partially utilized, which leads to a sharp fall in the average heat-transfer coefficients.

The published information on Γ_{min} is contradictory and incomplete [3–9]. Opposing views are held regarding the effect of the temperature regime on Γ_{min}; the effect of the roughness and material of the wall surface has not been established, nor has that of the physical properties of the irrigating liquid and the design of the distributor.

Accordingly, we have experimentally investigated the relation between the above-mentioned factors and Γ_{min}. The experimental apparatus, the method of investigation, and certain preliminary results were described in [1, 2]. As in [6], it was noted that the value of Γ_{min} depends on whether the wall surface is dry ($\Gamma_{min\,1}$) or prewetted ($\Gamma_{min\,2}$). The differences of 450–1200% obtained depend on the inlet temperature of the liquid t_{in}, the temperature difference between the heated wall and the film, the roughness and state of contamination of the wall, the material of the experimental tube, and the design of the distributor. The experimental dependence of $\Gamma_{min\,1}$ and $\Gamma_{min\,2}$ on wall temperature is presented in Fig. 1 for a smooth tube of 1Cr18Ni10Ti stainless steel irrigated with distilled water at film inlet temperatures t_{in} = 20, 44.3, and 62.9°C. This discrepancy between the values of $\Gamma_{min\,1}$ and $\Gamma_{min\,2}$ can be attributed to contact angle hysteresis [2, 6]. As the average temperature t_w of the wetted wall rises, the minimum irrigation density increases considerably. Thus, at $t_{in} = 20°$ C and $t_w = 20°$ C, $\Gamma_{min\,2} = 14.87$ kg/m · hr, while at $t_w = 120°$ C, $\Gamma_{min\,2} = 496.7$ kg/m · hr (Fig. 1, curve a). As the temperature difference between the wall and the film increases, the irrigating liquid begins to gather into thickened filaments, between which a thinner film is maintained. With further increase in $\Delta t = t_w - t_f$, the film between these filaments first periodically, then completely disappears; the filaments grow even thicker, acquiring an oval shape, and flow in zigzags over the experimental tube.

The local thickening leads to a nonuniform temperature distribution in the liquid along the wetted perimeter of the tube; the temperature of the intermediate bands of liquid between the filaments approaches the temperature of the wall. This, in turn, leads to nonuniformity of the surface tension in different parts of the water film. The film usually disintegrates in the upper part of the tube near the distributor, where at the inlet the film has the lowest temperature; therefore, increasing t_{in} reduces the value of the minimum irrigation density (Fig. 1, curves a, b, and c). It should also be noted that at $t_w > 100°$ C these experimental curves do not have a descending branch, as in the relations proposed by Norman et al. [7, 8], whose experimental tube was only 152 mm long; their observations of wetting action in the lower part of the tube were obstructed since the inside wetted diameter of the tube was 22.14 mm. The nature of the relations obtained in our experiments with a tube approximately six times as long (591 mm) [sic] as in [7, 8] can be attributed to the fact that at the given flow rates and temperatures, as a result of boiling, "dry" spots appear in the lower part of the tube. These necessitate an

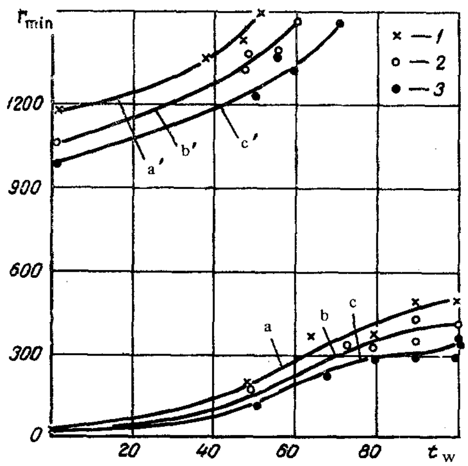

Fig. 1. Minimum irrigation densities $\Gamma_{min\,1}$ (curves a', b', and c') and $\Gamma_{min\,2}$ (curves a, b, and c) as a function of t_w for a smooth tube of 1Cr18Ni10Ti stainless steel at different film inlet temperature: 1) t_{in} = 20; 2) 44.3; 3) 62.9°C.

increase in irrigation density; i.e., in this case the disintegration of the film is displaced from the upper to the lowest part of the tube.

The density Γ_{min} also depends on the width of the distributor slit. Thus, at a slit width S = 0.15 mm $\Gamma_{min\,2}$ = 14.87 kg/m · hr, and at S = 0.5 mm $\Gamma_{min\,2}$ = = 8.23 kg/m · hr. This can be attributed to the more uniform distribution of liquid over the wetted perimeter in connection with the fact that as the wall temperature rises the concentricity of the slit is disturbed. Therefore, to obtain low values of Γ_{min} the distributor should ensure uniform distribution of liquid over the wetted perimeter of the tube and good wetting in the upper part of the tube, which can be achieved by increasing the angle of twist at the distributor outlet and by a suitable choice of slit width S.

Contamination of the wall surface also leads to a considerable change in Γ_{min}. Grease prevents the uniform wetting of the surface and Γ_{min} increases sharply. It can be removed by washing the tubes with a boiling water film at large irrigation densities or with degreasing agents (weak warm soda solution, acetone, etc.). On the other hand, a coating of corrosion on the tube appreciably reduces the value of Γ_{min}.

The value of Γ_{min} is also affected by the tube material. The wettability of a smooth tube of stainless steel was inferior to that of an identical tube of steel 20 (Fig. 2, curves a and b, respectively). Other things being equal, the difference in the values of Γ_{min} for these tubes increased with increase in wall temperature: at t_w = 20° C $\Gamma_{min\,2}$ for the tube of stainless steel was 14.87 kg/m · hr, while for steel 20 it was 9.7 kg/m · hr, and at t_w = 120° C the corresponding values were 496.7 and 348.1 kg/m · hr. This may be attributable to changes in the contact angle.

The change in Γ_{min} was especially noticeable in working with rough tubes, since Γ_{min} itself is affected by the type of artificial roughness, the height of the asperities, their configuration, and their density (Fig. 2, curves c, d, and e). The values of $\Gamma_{min\,2}$ obtained for distilled water and rough tubes increased particularly strongly, as compared with the smooth tube, with increase in t_w at $\Delta t > 35°$ C. These effects are attributable both to the considerable change in contact angle in the presence of roughness and to a certain increase in irrigation density needed to cover the asperities with a film.

The experimental data obtained may prove useful both in connection with the operation of existing film apparatus and in connection with the design of new equipment.

NOTATION

S is the width of the distributor slit, m (mm); t_{in} is the temperature of the irrigating liquid on entering

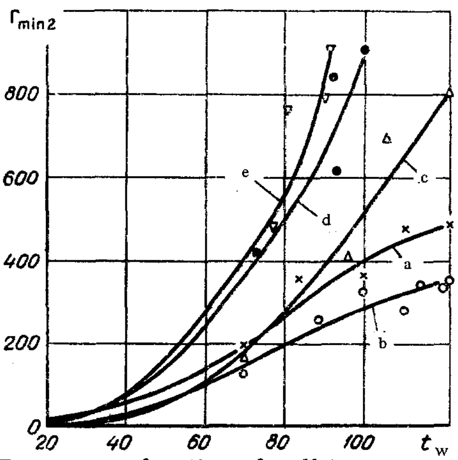

Fig. 2. $\Gamma_{min\,2}$ as a function of wall temperature for smooth and rough tubes at t_{in} = 20° C: curve a) smooth stainless steel tube; b) smooth steel 20 tube; c) tube with transverse knurling 0.22 mm deep, pitch 1.01 mm; d) tube with longitudinal knurling 0.22 mm deep, pitch 0.50 mm; e) tube with cross knurling 0.16 mm deep, pitch 0.97 mm.

the distributor, deg; t_f is the average temperature of the film, deg; t_w is the average temperature of the wetted surface of the experimental tube wall, deg; Δt is the difference between the average temperatures of the wall and the film, deg; Γ_{min} is the minimum irrigation density, m^2/sec(kg/m · hr); $\Gamma_{min\,1}$ and $\Gamma_{min\,2}$ are the same for dry and prewetted wall surfaces, respectively, m^2/sec(kg/m · hr).

REFERENCES

1. I. I. Chernobyl'skii, Yu. M. Tananaiko, and E. G. Vorontsov, collection: Chemical Machine Building [in Russian], Tekhnika, Kiev, no. 2, 1965.

2. I. I. Chernobyl'skii and E. G. Vorontsov, Khimichna promyslovist, no. 4, Kiev, 1965.

3. R. Bressler, Forschungsberichte des Landes N–W, no. 770, 1–50, 1960.

4. D. E. Hartley and W. Murgatroyd, Int. J. Heat Mass Transfer, 7, 1003–1015, 1964.

5. T. Hobler and W. Granowski, Chem. stosow., 4, 425–446, 1959.

6. T. Hobler and Lu-Sin-Zu, Chem. stosow., 5, 153–168, 1961.

7. W. S. Norman and D. T. Binns, Trans. Inst. Chem. Engrs., 38, 294–300, 1960.

8. W. S. Norman and V. McIntyre, Trans. Inst. Chem. Engrs. 38, 301–307, 317–323, 1960.

9. J. Ploeg, Zeitschr. für d. gesamte Kälte-Industrie, 37, 63–66, 1930.

11 October 1967 Polytechnic Institute, Kiev