COMMUNICATIONS TO THE EDITOR

Heat Transfer to Falling Water Films Containing Surface-Active Agents

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The application of the classical Nusselt analysis (*3*, *4*) to the process of heat transfer to a liquid film falling vertically under gravity is known to result in heat transfer coefficients grossly different from experimentally determined values (*2*). It is generally thought that surface waves significantly contribute to the heat transfer process so that their suppression using surface-active additives should result in measurable changes in the heat transfer coefficients.

Strobel and Whitaker (*5*) have demonstrated that the addition of surfactant to a falling film system results in a reduction in the free surface velocity with a consequent increase in the contact time. Thus two opposing effects result from the addition of a surfactant. First, the heat transfer coefficient should fall as a result of the suppression of mixing, while, on the other hand, the coefficient is tending to increase as a result of the extension of the contact time. An experimental investigation of these effects is reported.

EXPERIMENTAL DETAILS

The apparatus used in the current investigation is a development of similar equipment used by Ponter (*6*) and by Haigh (*1*), which consists of 1.112 in. O.D. copper pipe, 2 ft. in length, with provision for the uniform distribution of fluid on the tube periphery using a variable orifice distributor. The heating system was water circulated through the inside of the pipe.

A stringent cleaning procedure was followed to ensure reproducible results. After experimentally determining minimum wetting rate conditions, the film fluid flowed continuously over the copper surface at flow rates in excess of these values. The vertical orientation of the tube was checked at frequent intervals. Temperature measurements were made using calibrated mercury in glass thermometers while measurements of the film flow rate were made with a calibrated cylinder and

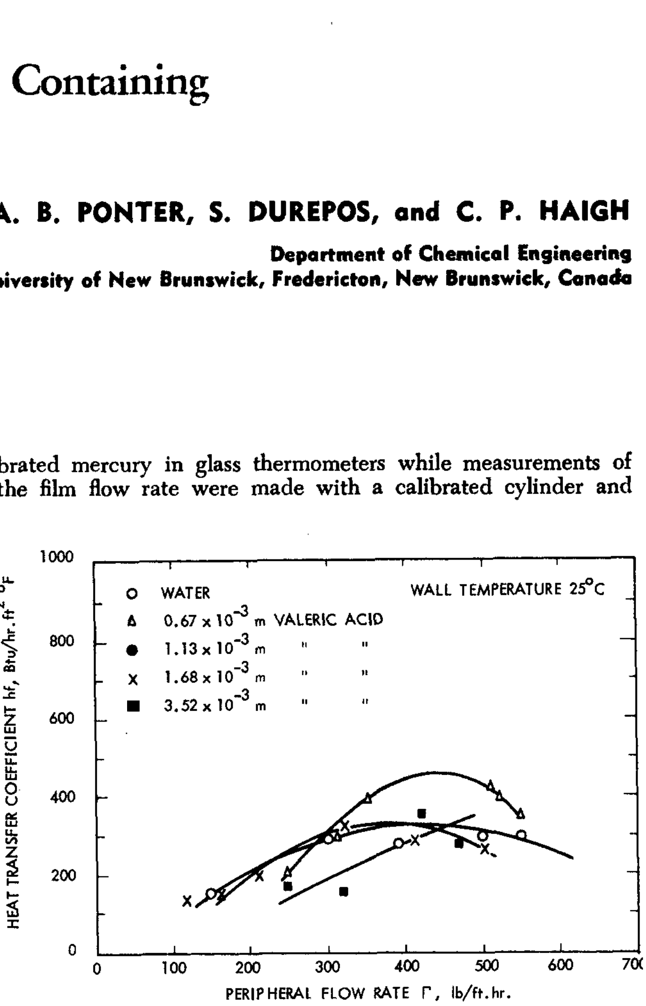

Fig. 1. Experimental film heat transfer coefficients, $T_W = 25°C$.

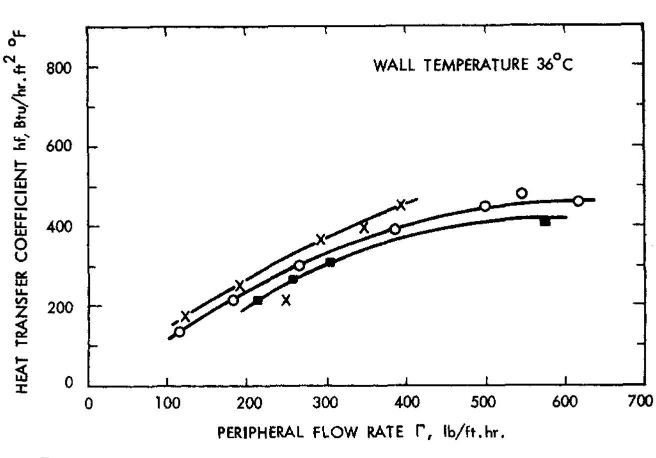

Fig. 2. Experimental film heat transfer coefficients, $T_W = 36°C$.

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stopwatch technique. The latter reading was taken during steady heat transfer conditions.

The procedure adopted for the operation of the equipment demanded that an appreciably constant film inlet condition be maintained. Inlet temperatures were within the range 8.5° to 11°C, with the values at a given wall temperature being constant. Rates of heat transfer to a number of film mass flux values were then obtained by measuring film inlet and outlet temperatures. The wall temperature was taken to be that of the heating liquid. This process was repeated for a number of wall temperature values. Experiments were also conducted with solutions of valeric acid, with the equipment being dismantled and cleaned after each test run.

EXPERIMENTAL RESULTS

The overall heat transfer coefficient was based on the arithmetic mean temperature difference: thus

$$Q = \Gamma \cdot \pi D \cdot Cp\ (T_o - T_i) = U \cdot \pi DL\ (T_w - T_m) \qquad (1)$$

Individual heat transfer coefficients were calculated from the measurements by application of the Dittus-Boelter equations to the single phase heating flow to evaluate the heating coefficient. Since mean values are being considered the effect of variations on the inside heat transfer coefficient, and hence in the wall temperature, are nullified. The filmside heat transfer coefficient was obtained from

$$\frac{1}{h_f} = \frac{1}{U} - \frac{1}{h_i} \qquad (2)$$

since both the radii effect and the thermal resistance of the tube can be neglected. Calculation of the accuracy of the overall coefficient using the principle of differential error superposition indicated an experimental uncertainty of approximately 7% root mean square.

Experimentally determined values of the heat transfer coefficient for water and water/valeric acid mixtures over a range of concentrations are presented in Figures 1 to 3 where wall temperature is used as a parameter. The experimental scatter in Figures 2 and 3 shows a significant reduction over that of Figure 1 because of the proportionally small temperature measurement errors as the overall temperature differences increase. In all cases the addition of trace quantities to valeric acid results in an enhanced heat transfer rate. As the valeric acid concentration is increased, however, the heat transfer coefficient falls and is eventually below that for pure water.

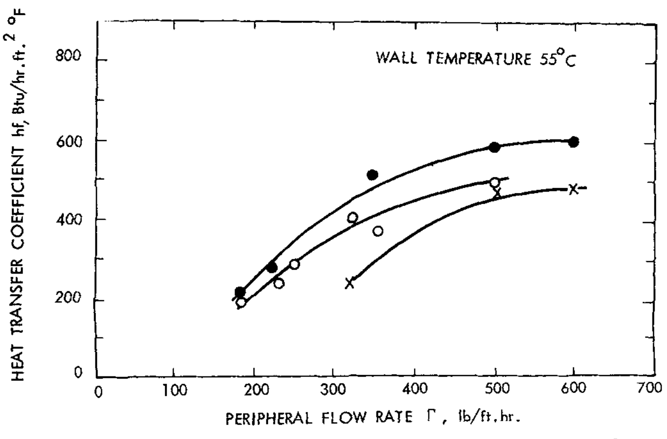

Fig. 3. Experimental film heat transfer coefficients, $T_W = 55°C$.

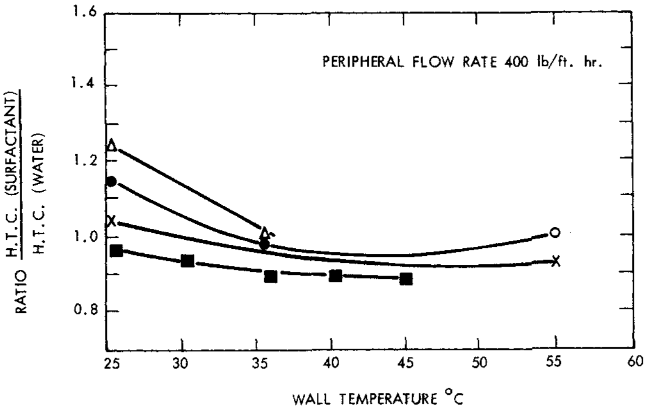

Fig. 4. Effect of surfactant on heat transfer coefficient, $\Gamma = 400$ lb./(ft.)(hr.).

The experimental data are additionally presented as Figure 4 where the ratio of the heat transfer coefficient for surfactant runs to the heat transfer coefficient for pure water is presented as a function of wall temperature with a constant peripheral mass velocity of 400 lb./(ft.)(hr.). The same initial increase in the coefficient is apparent. The tendency of the data toward unity at elevated temperature shows that the surfactant effect is being nullified by the increased potential for surface waves as the surface tension reduces with an increase in temperature.

DISCUSSION

It has earlier been noted that the addition of valeric acid to a falling film system will enhance the heat transfer coefficient by increasing the contact time and reduce it as a result of the suppression of surface waves. It has been shown that at low concentration the former effect is more pronounced, but that as the concentration is increased the effect of surface wave suppression becomes more important. These observations are in line with the predictions of Strobel and Whitaker (5).

NOTATION

C_p = specific heat
D = diameter
h = heat transfer coefficient (individual)
m = molar concentration
L = length
Q = heat load
T = temperature
U = heat transfer coefficient (overall)
Γ = peripheral flow rate

Subscripts

f = film value
i = inside (tube) or inlet
m = arithmetic mean
o = outlet
w = wall value

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