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MINIMUM WETTING RATES FOR FALLING-FILMS

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ABSTRACT

Falling film evaporators are extensively used in the food industry for their ability to handle heat sensitive materials like milk and fruit juice. A coherent film is required to maintain high heat transfer efficiency and to minimise fouling. Given that the tube wall temperatures in dairy evaporators are typically less than 70 °C it seems very likely that most evaporator fouling is not heat transfer fouling but is due to film breakdown. The minimum flow rate required to maintain a film is known as the minimum wetting rate which is defined as the minimum mass flow rate per unit circumference. The first significant theoretical analysis was that of Hartley and Murgatroyd [1] who considered the minimum wetting rate required to wet a dry area under isothermal vertical flow without evaporation. Their relationship can be expressed in terms of two dimensionless groups in equation (1) where a = 1.69 and b = 0.6.

$$\frac{\Gamma_{\min}}{\mu} = a\left(\frac{\left(\sigma\left(1-\cos\theta\right)\right)\rho^{1/3}}{\mu^{4/3}g^{1/3}}\right)^{b} \tag{1}$$

This analysis has been enhanced [2] to include other effects such as heat flows. However the theoretical analyses are not well supported by empirical data that apply to evaporator conditions.

In this work minimum wetting rates in a 1 m long, 48 mm internal diameter, vertical, stainless steel tube were determined for water, and aqueous solutions of glycerol, alcohol, and calcium chloride. These substances were chosen to give a wide range of properties such as viscosity (from 0.5 to 39 mPa.s), density (950 – 1410 kg m^{-3}), surface tension (35 to 90 mN m^{-1}) and contact angle (36 – 97°) so that the right side of equation (1) varied from 20 to 8200. It was found that initial distribution of the liquid at the top of the tube was critically important and after several trials a 40 mm long tubular section of unglazed ceramic with the same internal diameter as the stainless steel was used. It was placed on top of the tube to ensure full distribution with vertical flow before the liquid flowed onto the stainless steel. The minimum wetting rates were measured under isothermal conditions at 25 °C or 60 °C.

The results obtained from six distinct solutions fitted equation (1) with an R^2 value of 0.996 but with a = 0.216 and b = 0.771. The change in b seems small but the original coefficients gives the wetting rate as proportional to $\mu^{0.2}$ while the new coefficients gives proportionality to $\mu^{-0.025}$ showing almost no influence of viscosity. Given the range of viscosities encountered during evaporation (0.4 to 100 mPa·s perhaps), the difference between the two sets of coefficients for equation (1) is significant.

The high R^2 value and the low uncertainty of the data support the need for a new examination of the theory.

[1] Hartley, D.E. and Murgatroyd, W. (1964) Criteria for the break-up of thin liquid layers flowing isothermally over solid surfaces, *International Journal of Heat and Mass Transfer*, **7,** 1003-1015.

[2] Hoke, B.C. and Chen, J.C. (1992) Thermo capillary breakdown of falling film liquid films, *Industrial and Engineering Chemistry Research*, **31**, 688-694.