Further Developments of Dropwise Condensation Theory

S. S. Sadhal. In this recent contribution by Tanaka, some progress has been made in the treatment of ensembles of droplets on solid surfaces. It must be pointed out, however, that in Tanaka’s analysis, Mikic’s expression for the heat flow across a single droplet is used outside its range of validity. The heat flow is across a hemispherical droplet with a uniform base temperature given by Umur and Griffith [2] to be

\[ \frac{Q}{R k_e (T_v - T_s)} = \frac{2\pi}{m} \sum_{m=1}^{\infty} \frac{m(2m + 1)}{1 + (k_e/\alpha m)} \left[ \int_0^1 \Phi_m(x) dx \right]^2, \]

where \( R \) is the droplet radius, \( k_e \) is the thermal conductivity of the liquid, \( T_v \) is the vapor temperature, \( T_s \) is the droplet base temperature, and \( h \) is the heat-transfer coefficient at the liquid-vapor interface. A useful approximation for (1) was obtained by Mikic [1] to be

\[ \frac{Q}{R k_e (T_v - T_s)} = \frac{4\pi}{1 + 2k_n/\alpha R}. \]

As pointed out by Sadhal [3], equation (2) is only valid for \( Bi = h R / k \) < 10. To illustrate this point, equations (1) and (2) are plotted on the same graph in Fig. 1. It can be clearly seen that Mikic’s approximation holds very well up to \( Bi = 10 \). For \( Bi > 10 \) a strong deviation is observed, and equation (2) levels off to a value \( 4\pi \). Equation (1), on the other hand, appears to behave like \( \Phi_n(Bi) \).

It is quite appropriate to note here that for metallic condensers (thermal conductivity, \( k_n \sim 100 k_f \)), it was shown by Sadhal and Plesset [4] that the effect of the solid becomes quite significant for \( Bi > 1000 \). At such large values of \( Bi \), the droplet base temperature, therefore, cannot be assumed to be uniform.

In conclusion, since Tanaka has used values of \( Bi \) up to \( 10^4 \) in equation (2), the results so obtained are questionable.

Additional References


Author’s Closure

I acknowledge that in the strict sense Mikic’s expression is only valid for \( Bi < 10 \), that is for \( \xi < 5 \xi_l \) in my Nomenclature. Under actual dropwise condensation including that of water, however, the size of thermodynamic critical droplet, \( r_c r_l \), is over two orders of magnitude smaller than the size \( 5r_l \) in my Nomenclature which corresponds to \( Bi = 10 \) (see Table 1 of my paper), and heat is transferred mainly by microscopic active drops belonging in the range \( Bi < 10 \), though a large percentage of the condensing surface is occupied by larger drops. Thus, whether we adopt Umur-Griffith’s exact prediction or Mikic’s approximation, we obtain almost the same value of heat-transfer coefficient for dropwise condensation. From a more theoretical point of view, it will be understood in reviewing the theory [1] that, whatever profile we may assume for the substantial growth rate \( r_e \) in the size range where \( r_e \) becomes over an order of magnitude smaller than the total rate of drop growth rate \( r_e \), results of the drop-size distribution \( N \) and the drop growth rate \( r_e \) predicted from the basic integro-differential equations remain entirely unchanged.

As for the effects of a finite thermal conductivity of a condenser material deviation of the substantial growth rate \( r_e \) due to ununiformity of the droplet base temperature in a large drop range is not important to the resultant heat-transfer coefficient for the reason stated above; but the so-called constriction resistance proposed by Mikic [2] seems to be worth of much attention. In this respect, Hannemann and Mikic [6] have shown that in the case of dropwise condensation of steam onto a copper surface the constriction resistance is almost negligible.

Additional Reference


Fig. 1 Nusselt number \( Nu = Q/\left(k_n R(T_v - T_s)\right) \) as a function of \( Bi = h R / k_n \); comparison of Umur-Griffith prediction with Mikic’s approximation.