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LETTERS TO THE EDITORS

EFFECT OF RADIATION ON EVAPORATING DROPLETS

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IN A RECENT paper and report Yuen and Chen [1, 2] report measurements of heat transfer to water and methanol droplets in an atmospheric vertical hot air tunnel. It appears that the radiative heat transfer to the droplets was underestimated, and provision was not made for radiation influencing the mass-transfer number B.

First, radiative heating was computed based upon a tunnel wall radiosity of $\varepsilon_w \sigma T_w^4$, with no account of interreflections. A more reasonable estimate is one including N interreflections.

$$Q_R = 2\pi R^2 \varepsilon_d \Big\{ \sigma T_s^4 (1-\cos\theta_1) + \int_{\theta_1}^{\pi/2} \rho^{N(\theta)} \sigma T_s^4 \sin\theta \, d\theta + \int_{\theta_1}^{\pi/2} (1-\rho^{N(\theta)}) \sigma T_w^4(\theta) \sin\theta \, d\theta + \sigma T_c^4 [1-\cos\theta_1'] + \int_{\theta_1'}^{\pi/2} \rho^{N(\theta')} \sigma T_c^4 \sin\theta' \, d\theta + \int_{\theta_1'}^{\pi/2} (1-\rho^{N(\theta')}) \sigma T_w^4(\theta') \sin\theta' \, d\theta' - 2\sigma T_d^4 \Big\}, \quad (1)$$

where

$$N(\theta) = \mathrm{IF1X}\left[\frac{1}{2}\left(\frac{L}{r}\tan\theta + 1\right)\right], \quad (2)$$

and $N(\theta')$ is based upon θ' and L'. The FORTRAN function IF1X means the value of N is truncated to the closest smaller integer. In writing equation (1) we have assumed a centrally-located small spherical drop of radius R a distance L' ($=76$ mm) below a black body at temperature T_c and a distance L ($=280$ mm) above one at T_s. The tunnel, which was actually square, is approximated as circular to simplify the calculation. When the tunnel radius r is set by equating the circular and actual cross-sectional areas, the approximation is quite reasonable [3]. Polarization and scattering are also neglected for simplicity, again reasonable. The distance y below the sphere is related to θ through $y = r\cot\theta$, thus relating $T_w(y)$ to $T_w(\theta)$.

Yuen and Chen gave values of $R = 3.175$ mm, $\varepsilon_d = 0.95$, $\varepsilon_w = 0.70$, and for $T_s = 1248$ K,

$$T_w[\mathrm{K}] = 728 + 120.8(y/L) + 74.2(y/L)^2. \quad (3)$$

We calculate Q_R to be 1.99 W vs 1.43 W. As one would expect, the more correct value of Q_R is roughly $1/\varepsilon_w$ greater than what was calculated before, using $\varepsilon_w \sigma T_w^4$ as the wall radiosity; that is, the wall radiosity is more nearly that of a black body.

The values of Q_R being underestimated impact upon the results (1) directly by leading one to believe the observed evaporation is due to more convective heating than is actually the case and (2) indirectly by increasing the mass-transfer or blowing number. Fortunately these two impacts largely cancel, leaving the correlation proposed by Yuen and Chen intact. First, the Nusselt number derived from the data is to be lowered, because of the increased value of Q_R.

$$Nu = \frac{(Q-Q_R)2R}{4\pi R^2 k}. \quad (4)$$

Second, the mass-transfer number B is increased by the radiation [4–6]

$$B = \frac{h_s - h_d}{L(T_d) - q_R/\dot{m}} = \frac{h_s - h_d}{L(T_d)}\left[1 + \frac{Q_R}{Q_c}\right]. \quad (5)$$

The first effect causes the true values of Nu to be approximately 6–8% lower than reported by Yuen and Chen for $T_s = 1250$ and 1233 K respectively. The second effect, which was neglected entirely, causes the true $(1+B)$ correction factor to increase by 8 and 9% respectively, leaving the correlation

$$Nu(1+B) = 2 + 0.6 Re_M^{1/2} Pr_f^{1/3},$$

essentially intact.

It should be noted that in high temperature surrounds, a liquid droplet can receive radiant heating much greater than the convective heating. For example, if the Yuen and Chen tunnel had been insulated such that all surfaces viewed by the droplet were at $T_s = 1248$ K, then the droplet would have received 17.3 W instead of 1.99 W, and this value would be more than twice that of their data for convective heating.

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