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COMMENT ON "HEAT TRANSFER THROUGH THE AXIALLY SYMMETRIC BOUNDARY LAYER ON A MOVING CIRCULAR FIBRE"

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IN A RECENT paper [1] Bourne and Elliston reviewed the technology on heat transfer from continuous moving surfaces to stagnant surroundings. The authors compared a Nusselt number based on the experimental data of Alderson, Caress and Sager [2], obtained on cooling glass filament, with a theoretical Nusselt number obtained by solving the isothermal boundary layer equations using the approximate v. Kármán–Pohlhausen integral method.

Bourne and Elliston assume that the only heat losses are those due to forced convection. As a result, their theoretical values show no filament radius dependency, as do the experimental ones. Further, their theory predicts heat transfer coefficients that are as much as 15 per cent lower than those observed by Alderson, Caress and Sager.

The radiation losses from transparent and semi-transparent materials such as glass filaments which the authors have not accounted for in their calculations can, at times, be quite significant. To demonstrate this point, we estimate the radiant energy transfer for a semi-transparent filament with the following assumptions: (1) no radial temperature gradient in the filament, (2) no radiant scattering within the filament, (3) negligible polarization effects, and (4) physical properties of the glass that are independent of temperature. The experimental data of Alderson, Caress and Sager are contained in a company confidential report. Therefore, we assume that the glass they used can be classified in one of the following cases: (1) a gray opaque glass, with surface radiation only, (2) a typical borosilicate glass, with some volume emission [3], or (3) a highly transparent glass, such as ITRAN 1, a MgF_2 glass [4].

CASE 1—GRAY OPAQUE GLASS

The radiation Nusselt number, which we assume is additive with the convection Nusselt number as calculated by Bourne and Elliston, is given as:

$$Nu_r = Q/k\,\Delta T = (Q/A)(2\pi RL/k\,\Delta T) \tag{1}$$

where Q/A is the radiant heat flux, given as:

$$Q/A = \sigma\varepsilon(T_f^4 - T_a^4)$$

where σ is the Stefan–Boltzmann constant, $0{\cdot}1714 \times 10^{-8}$ Btu/ft^2 h °R^4, ε is the emissivity, and T_f and T_a the temperatures of the filament and the stagnant air *seen by the filament*, respectively. We assume, as do Bourne and Elliston, that the average filament temperature is 300°C (1032°R) and the average air temperature for the determination of air physical properties is 160°C (780°R). The filament is assumed to radiate to an air temperature of 20°C (528°R). Evaluation of the gray opaque glass radiant Nusselt number, using equation (1) is:

$$Nu_r = 34{\cdot}22\,R\ (R \text{ in cm}). \tag{2}$$

Thus, the radiation Nusselt number is linear with respect to filament radius, for this case. This result, combined with the convection Nusselt number of 0·88, which is independent of filament radius, is represented in Fig. 1 for the filament radius given by Bourne and Elliston.

CASE 2—BOROSILICATE GLASS

If we now consider that the filament radiation properties are wavelength dependent, the net radiant interchange between the filament and its surroundings is given as [5–7]

$$Q = \int_0^{\infty} A\varepsilon_1(\alpha, R)\,[e_{\lambda b,1}(\lambda, T_1) - e_{\lambda b,2}(\lambda, T_2)]\,d\lambda \tag{3}$$

where L is a characteristic fiber length, here assumed to be unity, ε_1 is the emissivity of the filament (assumed to be dependent on R, the filament radius and α, the absorption coefficient) λ is electromagnetic wavelength, $e_{\lambda b,1}$ is the wavelength-dependent blackbody emissive power of the filament, and $e_{\lambda b,2}$ is the same for the surroundings. Following Gardon's suggestion, we approximate the very irregular curve for the absorption coefficient as a function of wave-

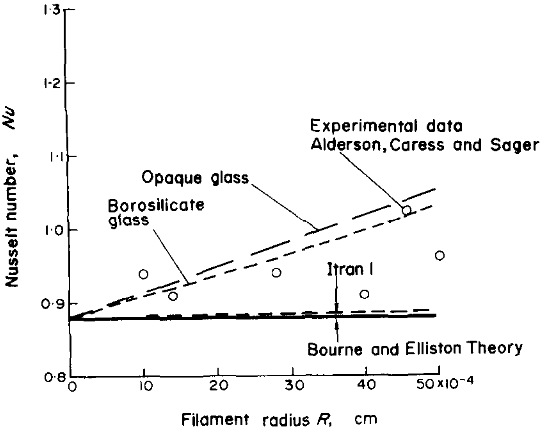

FIG. 1. Comparison of experimental and theoretical values of Nusselt number for variable radius; Fig. 3 as reproduced from Bourne and Elliston [1], with radiation corrections included.

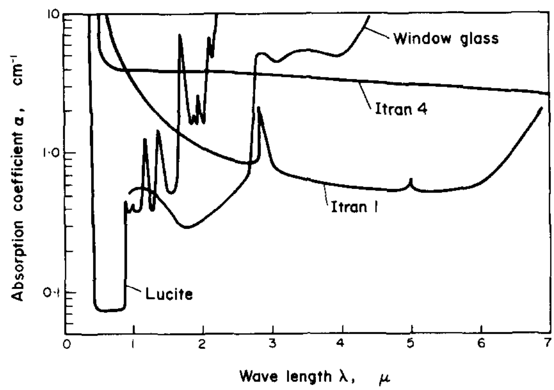

FIG. 2. Absorption spectra for a number of semi-transparent glasses.

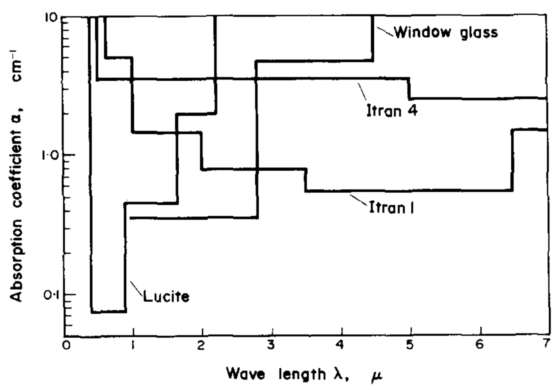

FIG. 3. Approximated absorption spectra for a number of semi-transparent glasses as per Gardon [3].

length (Fig. 2) with a series of step functions, as shown in Fig. 3. With this simplification for "window glass" equation (3) becomes:

$$Q/2\pi RL = Q/A = \sigma T_1^4\left[6{\cdot}09\,R\int_{0\cdot8}^{2\cdot75}\frac{e_{\lambda b,1}(\lambda, T)}{\sigma T_1^4}\,d\lambda + 78{\cdot}3\,R\int_{2\cdot75}^{4\cdot5}\frac{e_{\lambda b,1}(\lambda, T)}{\sigma T_1^4}\,d\lambda + 0{\cdot}91\int_{4\cdot5}^{\infty}\frac{e_{\lambda b,1}(\lambda, T)}{\sigma T_1^4}\,d\lambda\right] - 0{\cdot}91\,\sigma T_2^4 \quad (4)$$

and the radiation Nusselt number becomes, for an average filament temperature of 300°C and an air temperature of 160°C:

$$Nu_r = 0{\cdot}00355\,(7770 + 1{\cdot}45 \times 10^5 R)\,R \quad (R \text{ in cm}) \quad (5)$$

The radiation Nusselt number for conventional borosilicate glass has nonlinear dependency on filament radius. This result, combined with the radius-independent convection Nusselt number of Bourne and Elliston, is shown in Fig. 1.

CASE 3—TRANSPARENT GLASS

If the glass filament is nearly transparent, such as ITRAN 1 shown in Fig. 2, the radiation Nusselt number is very small. Again we approximate the irregularly shaped absorption curve of Fig. 2 with a series of step functions, as shown in Fig. 3. Using this, equation (3) becomes:

$$Q/2\pi RL = Q/A = \sigma T_1^4\left[26{\cdot}1\,R\int_{1\cdot0}^{2\cdot0}\frac{e_{\lambda b,1}}{\sigma T_1^4}\,d\lambda + 13{\cdot}9\,R\int_{2}^{3\cdot5}\frac{e_{\lambda b,1}}{\sigma T_1^4}\,d\lambda + 9{\cdot}57\,R\int_{3\cdot5}^{6\cdot5}\frac{e_{\lambda b,1}}{\sigma T_1^4}\,d\lambda + 26{\cdot}1\,R\int_{6\cdot5}^{\infty}\frac{e_{\lambda b,1}}{\sigma T_1^4}\,d\lambda\right] - \sigma T_2^4\left[13{\cdot}9\,R\int_{2}^{3\cdot5}\frac{e_{\lambda b,1}}{\sigma T_2^4}\,d\lambda + 9{\cdot}57\int_{3\cdot5}^{6\cdot5}\frac{e_{\lambda b,1}}{\sigma T_2^4}\,d\lambda + 26{\cdot}1\,R\int_{6\cdot5}^{\infty}\frac{e_{\lambda b,1}}{\sigma T_2^4}\,d\lambda\right]. \quad (6)$$

Again, for an average filament temperature of 300°C and an average air temperature of 160°C, the radiation Nusselt number becomes:

$$Nu_r = 0{\cdot}00355\,(3420\,R)\,R \quad (R \text{ in cm}) \quad (7)$$
$$= 121{\cdot}6\,R^2.$$

For the very small diameter filaments considered, the radiation Nusselt number is a negligible correction to the convection Nusselt number, as shown in Fig. 1.

Apparently then, for materials that have very high thermal diffusivities as compared with that of the cooling medium, the assumption of isothermal cooling as described by Bourne and Elliston [1] is satisfactory for the prediction of heat transfer from continuous surfaces. However, all necessary energy losses, such as radiation, must be included in the calculations, for, as is demonstrated in this paper, these corrections can be quite significant.

ACKNOWLEDGEMENT

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A GAS VOLUMETRIC TECHNIQUE FOR THE MEASUREMENT OF HEAT TRANSFER COEFFICIENT IN POOL BOILING

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NOMENCLATURE

h, boiling heat transfer coefficient;
K, thermal conductivity;
z, length;
N, air moles;
P, pressure;
R, Avogadro constant;
r, radial coordinate;
R, radius;
T, temperature;
T_{CW}, temperature of cooling water inlet;
T_{BW}, temperature of water boiling outside the evaporator;
T_{PE}, temperature of outer wall of the evaporator;
T_P, temperature of the inner wall of the evaporator;
V, volume;
W, power supply [W];
W_{diss}, power dissipated in the copper electrode;
z, axial coordinate.

Greek letters

α, temperature coefficient of thermal conductivity.

Subscripts

1, radius of the copper electrode;
2, inner radius of the evaporator;
3, outer radius of the evaporator;

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