TECHNICAL NOTE

Correlation formulas for mixed convection heat transfer in saturated porous media

D. A. Nield
Department of Engineering Science, University of Auckland, Auckland, New Zealand

The purpose of this note is to suggest some amendments to recently published correlation formulas for mixed convection heat transfer in saturated porous media.

For localized heating in a horizontal layer, Lai and Kulacki (1991) noted that, when an effective thermal conductivity was introduced, their experimental data were correlated by

$$\frac{Nu_D}{Pe_D^{0.5}} = \left[1.895 + 0.200\left(\frac{Ra_D}{Pe_D^{1.5}}\right)\right]^{0.375} \quad (1)$$

where Nu_D, Pe_D, and Ra_D are the Nusselt, Péclet, and Rayleigh numbers based on a heater length D. For comparison, a correlation obtained from numerical solutions was

$$\frac{Nu_D}{Pe_D^{0.5}} = \left[1.917 + 0.210\left(\frac{Ra_D}{Pe_D^{1.5}}\right)\right]^{0.372} \quad (2)$$

For localized heating in a vertical annulus, Choi, Lai, and Kulacki (1989) obtained, on the basis of numerical calculations, the following correlations.

Isothermal source, aiding flow:

$$\frac{Nu}{Pe^{0.5}} = (3.373 + \gamma^{0.566})\left[0.0676 + 0.0320\frac{Ra}{Pe}\right]^{0.489} \quad (3)$$

Isothermal source, opposing flow:

$$\frac{Nu}{Pe^{0.5}} = (2.269 + \gamma^{0.511})\left[0.0474 + 0.0469\frac{Ra}{Pe}\right]^{0.509} \quad (4)$$

Constant-flux source, aiding flow:

$$\frac{Nu}{Pe^{0.5}} = (7.652 + \gamma^{0.892})\left[0.0004 + 0.0005\frac{Ra}{Pe^2}\right]^{0.243} \quad (5)$$

Constant-flux source, opposing flow:

$$\frac{Nu}{Pe^{0.5}} = (4.541 + \gamma^{0.787})\left[0.0017 + 0.0021\frac{Ra}{Pe^2}\right]^{0.253} \quad (6)$$

Here Nu, Ra, and Pe are defined in terms of the annular gap, and γ is a radius ratio.

These formulas are reproduced in the survey article by Lai, Kulacki, and Prasad (1991) and in the monograph by Nield and Bejan (1992).

When the Rayleigh number is increased to large values, one would expect that the effect of forced convection would become negligible in comparison with the effect of natural convection, and consequently the Nusselt number should become independent of the Péclet number as the Rayleigh number becomes large. Accordingly, it is suggested that the final exponents in Equations 1–6 be replaced by $\frac{1}{3}$, $\frac{1}{3}$, $\frac{1}{2}$, $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{4}$, respectively, and the other coefficients adjusted if necessary (the amount of adjustment should be small).

The correlation formulas as amended are preferable because they each contain one fewer arbitrary parameter than before. Also, one would expect that, in the range of large Rayleigh numbers, they would be more accurate than the original formulas.

References

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Address reprint requests to Professor Nield at the Department of Engineering Science, University of Auckland, Auckland, New Zealand.

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