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LETTER TO THE EDITORS

Comments on "Numerical studies of forced convection heat transfer from a cylinder embedded in a packed bed"

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In a recent paper by K. J. Nasr, S. Ramadhyani and R. Viskanta, the abstract contains the sentence, "The effect of decreasing Darcy number (*Da*) was an increase in the Nusselt number." Reading this aroused our interest, because the statement is in conflict with our expectation that decreasing the Darcy number, i.e. decreasing the permeability (with the global length scale *D* unchanged), would lead to a decrease in velocity and, hence, a decrease in heat transfer by forced convection, i.e. a decrease in Nusselt number (assuming the thermal conductivity and temperature scale are also unchanged). Accordingly, we looked closely at the paper.

We discovered that a factor ϕ (the porosity) had been omitted from the left-hand sides of equations (9) and (10). Since, as we quickly checked, ϕ is of order unity in the present situation, the source of the anomaly is not to be found here. In fact it is possible to patch up the paper by inserting a factor ϕ in the definitions of *Da* (denominator) and *Fs* (numerator), but it is much more preferable, and in accordance with standard practice, to divide equation (4) through by ϕ, and redefine p (which is absent from the author's nomenclature list) and μ', the new pressure, p/ϕ, will then denote the fluid pressure and μ'/ϕ will denote the usual effective viscosity.

Looking further, we noted that the authors have in fact found from their calculations that *Nu* decreases with *Da* if the Reynolds number Re_D is held constant (their Table 1, p. 2358), where Re_D is defined by $Re_D = \rho U_\infty D/\mu$, where ρ, μ are the fluid density and viscosity, respectively, and U_∞ is the exterior stream velocity, assumed uniform. An explanation for the anomaly then became apparent. We had been thinking in terms of changing *Da* with the applied pressure gradient (which gives rise to U_∞) unchanged; increasing *Da* then implies that U_∞ is also increased and thus *Nu* is increased. In our opinion, the authors have made an unfortunate choice in presenting their results, and they have been remiss in not adding a qualification to the statement in their abstract that we have quoted above.

In our opinion it would be more sensible (and certainly less confusing to readers) if the authors had scaled the pressure, not using the scale ρU_∞^2, but rather using *GD*, where *G* is the applied pressure gradient, and the velocity using GD^2/μ instead of U_∞. If this is done, Re_D no longer appears in the nondimensional momentum equations and the difficulty is avoided. We are confident that the calculations will then show that *Nu* increases as *Da* increased.

We need not perform further calculations in order to back our claim for at least one case. Table 2 of the paper being discussed contains sufficient information to show this, as we now demonstrate. We introduce the notation $x = \log_{10} Da$, $y = \log_{10} Re_D$, $z = Nu$. We consider the case $Fs = 0$ and we assume that *Da* is sufficiently small so that the Brinkman term is small compared with the Darcy term. Then, approximately, $U_\infty = KG/\mu$ and so $Re_D = \rho KGD/\mu^2 = (\rho GD^3/\mu^2)Da$. Hence $y = x+c$, where $c = \log_{10}(\rho GD^3/\mu^2)$, and so

$$\frac{dz}{dx} = \frac{\partial z}{\partial x} + \frac{\partial z}{\partial y}\frac{dy}{dx} = \frac{\partial z}{\partial x} + \frac{\partial z}{\partial y}. \qquad (1)$$

Table 2 of Nasr *et al.* then gives the table of *z*-values:

	$x = -6$	-4	-2	0
$y = 2.3$	4.75	4.71	4.09	3.14
$y = 3.3$	14.92	14.41	9.54	6.70

Using forward differences, one then deduces the table of approximate values of $\partial z/\partial x$:

	$x = -6$	-4	-2
$y = 2.3$	-0.02	-0.31	-0.475
$y = 3.3$	-0.255	-2.435	-1.42

Similarly one deduces approximate values of $\partial z/\partial y$:

	$x = -6$	-4	-2	0
$y = 2.3$	10.17	9.70	5.45	3.56

Finally, using equation (1), one gets approximate values of dz/dx:

	$x = -6$	-4	-2
$y = 2.3$	10.15	9.39	4.975

All the entries are positive. This means that *Nu* increases with *Da*, if *G* is kept constant, for the case considered and the range of values for which results are available. We expect that this will also be true for the general case (nonzero Forchheimer number).

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AUTHORS' RESPONSE

This is in reference to the comments made by J. L. Lage and D. A. Nield on the above referenced paper. The authors of the paper would like to provide the following responses:

The local volume-averaged equations, equations (3)–(5), were based on a conventional form used by various investigators and extracted from Hsu and Cheng [12]. These equations were non-dimensionalized to obtain equations (8)–(11). The authors reviewed the dimensionless forms of the governing equations and believe that a factor ϕ has been omitted from the left-hand side of equations (9) and (10). Although p is absent from the nomenclature list, it was clearly noted in the paper (top of page 2335) that $p = \phi p_f$, where p_f is the volumetric average pressure of the fluid.

The authors agree that another approach could be taken for presentation of the results and analysis, although working with a pressure gradient is a possibility for expressing and presenting the results. In our opinion, however, it is much more convenient to work with Re_D and show similarities of the governing equations for porous media with the dimensionless Navier–Stokes equations.

We would like to thank Professors Lage and Nield for their careful scrutiny of our paper and for providing an alternative perspective on the results we have presented. We do believe that any confusion generated by the wording of the abstract would be resolved upon reading the paper.

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