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Letter to the Editor

Comments on 'A New Model for Viscous Dissipation in Porous Media Across a Range of Permeability Values', *Transport in Porous Media* **53**, 117–122, 2003

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The new model for viscous dissipation in a porous medium proposed by Al-Hadhrami *et al*. (2003) is probably adequate for most practical purposes. Their model is obviously correct in the limit of very small permeability and also in the limit of very large permeability, whereas the alternative model proposed by Nield (2000, 2002) breaks down in the latter limit.

However, in my view the new model is *ad hoc*. I question the introduction of the stress components in Equation (8) of Al-Hadhrami *et al*. (2003) for the case of a porous medium. It seems to me that the authors are assuming that the situation in a porous medium is exactly analogous to that in a clear (of solid material) fluid, in which the Navier–Stokes equation holds. In doing so they are taking no account of the fact that equations governing flow in a porous medium are obtained by averaging over an REV (representative elementary volume). There is no doubt that Equation (10) is correct, but can one work backwards to Equation (8)? In particular is the stress tensor introduced in Equation (8) something that can be properly defined by an REV average?

The drawbacks of the Nield model are obvious. It does not hold as the permeability tends to infinity, but then it is not expected to do so, because information is lost in the REV averaging process of quantities nonlinear in the velocity components, and this cannot be recovered when one tries to go in the reverse direction. Thus it is not surprising the Nield expression for the viscous dissipation lacks terms in the derivative of the velocity components, and can even take negative values.

I would argue that the Brinkman equation itself is breaking down when the Nield expression goes negative. The fact that the Brinkman equation formally transforms to the Navier–Stokes equation as the permeability tends to infinity does not imply that the equation continues to model in a uniform fashion the physics of the fluid flow. It is worth noting that the modern indiscriminant use of the Brinkman equation is a far cry from the use by Brinkman (1947a, b) himself, who was concerned with deriving a self-consistent relationship between the permeability and the porosity of a bed of spheres, rather than providing a general purpose momentum equation. Further discussion of the validity of the Brinkman equation may be found in Nield and Bejan (1999).

It seems to me that there is an urgent need to investigate further the validity of the Brinkman equation at very high values of the porosity. In my opinion the best way of doing this is to perform calculations, solving the Navier–Stokes equation at low and moderate values of the Reynolds number, for flow about an array of obstacles, and then comparing the results with those from a solution of the Brinkman equation itself. Dr Margot Gerritsen of Stanford University is currently engaged on an investigation of this type, but no results are yet available.

In the meantime it seems prudent to base predictions on each of the two models of viscous dissipation in turn. This has been done in one study of forced convection by Nield *et al.* (2003), who found that a significant difference between the predictions on the two models does not appear until the value of the relevant Darcy number exceeds 0.01.

In summary, it appears that whether one should model viscous dissipation on the Brinkman model by just a power-of-drag term, or a Darcy power term plus a term involving velocity derivatives, is still a moot point. However, it is clear that one should not use just the term involving velocity derivatives, as some authors have done in the past.

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References

Al-Hadhrami, A. K., Elliott, L. and Ingham, D. B.: 2003, 'A new model for viscous dissipation in porous media across a range of permeability values', *Transport in Porous Media* **53**, 117–122.

Brinkman, H. C.: 1947a, A calculation of the viscous force exerted by a flowing fluid on a dense swarm of particles, *Appl. Sci. Res. A* **1**, 27–34.

Brinkman, H. C.: 1947b, On the permeability of media consisting of closely packed porous particles, *Appl. Sci. Res. A* **1**, 81–86.

Nield, D. A.: 2000, Resolution of a paradox involving viscous dissipation and nonlinear drag in a porous medium, *Transport in Porous Media* **41**, 349–357.

Nield, D. A.: 2002, Modelling fluid flow in saturated porous media and at interfaces, in: D. B. Ingham and I. Pop (eds), *Transport Phenomena in Porous Media II*, Elsevier Science, Oxford, pp. 1–19.

Nield, D. A. and Bejan, A.: 1999, *Convection in Porous Media*, 2nd edn, Springer, New York, pp. 12–13.

Nield, D. A., Kuznetsov, A. V. and Xiong, M.: 2003, Effects of viscous dissipation and flow work on forced convection in a porous medium channel, *Int. J. Heat Mass Transfer* (submitted).