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Closure statements on the Brinkman-Forchheimer-extended Darcy model

The three articles listed below have appeared in the *International Journal of Heat and Fluid Flow* during the past five years. They discuss the limitations of the Brinkman-Forchheimer-extended Darcy model.

Fluid mechanics of the interface region between a porous medium and a fluid layer — an exact solution, K. Vafai and K. Kim, *Int. J. Heat Fluid Flow*, **11**, 254–256, 1990

The limitations of the Brinkman-Forchheimer equation in modeling flow in a saturated porous medium and at an interface, D. A. Nield, *Int. J. Heat Fluid Flow*, **12**, 269–272, 1991

On the limitations of the Brinkman-Forchheimer-extended Darcy equation, K. Vafai and K. Kim, *Int. J. Heat Fluid Flow*, **16**, 11–15, 1995

To assist interested journal readers in the comparison of the two viewpoints presented in these publications, the authors have agreed on the following closure statements.

Frank W. Schmidt, Editor-in-Chief

D. A. Nield

Department of Engineering Science, University of Auckland, Private Bag 92019, Auckland, New Zealand

Statements of Vafai and Kim (1995) need correction. (a) Nield (1991) reads "If one is not prepared to account for this porosity variation, then the use of the Brinkman term *may* [italics were never suggested by the author for the original version of the manuscript of Nield (1991)-ed.] be a complication that leads to no benefit", and "if in that case (for a *dense* [italics were never suggested by the author for the original version of the manuscript of Nield (1991)-ed.] medium) one has to include the Brinkman term, then porosity variation should also be allowed for". (b) Re naturally occurring media having porosity less than 0.6, Nield (1991) reads "exceptions are sponges and some forms of lava." Man-made materials are by definition not naturally occurring. (c) Nield (1991) introduced the "ideal medium" solely based on the effects of structure on the local time-derivative term. The consequent remarks of Vafai and Kim (1995) on the convective inertial term are not relevant.

Formal averaging methods inevitably involve a loss of information re the effect of geometry on flow.

On physical grounds, one expects that the appearance in the momentum equation of the Brinkman term, a vector, should not depend on whether the flow is 2-D. Thus one questions the assumptions underlying any purported demonstration to the contrary. The effective viscosity cannot be determined simply by averaging; it may differ substantially from the fluid viscosity (Givler and Altobelli 1994).

For dense media, scale analysis shows that the ratio of the advective term to quadratic drag term is normally small. Mathematical analysis based on averaging cannot decide whether the convective term should be retained. It is not necessary to retain the term to account for the development of momentum boundary layers; viscous diffusion can provide for this. If one retains the convective term unchanged then the prediction follows that momentum can be advected unobstructed by the solid matrix, contrary to physics. If one excludes the term entirely then one cannot account for the choking of flow of compressible fluids in porous media. I have suggested (Nield 1994) that the irrotational part of the term be retained but the rotational part be omitted. The retention of the convective term unchanged could lead to misleading predictions about turbulent flows.

My arguments on the porous medium/fluid interface in Nield (1991) stand. Vafai and Kim's argument on the normal stress condition collapses because they misquoted Chen and Chen (1992). They have confused tangential and normal coordinates. Modelling the solid matrix by a fluid of infinite viscosity is no help. The matching of tangential stress involves an indeterminant quantity. The Beavers-Joseph coefficient α allows for this and the possibility that an "effective viscosity" should be used in the matching (Martins-Costa and Saldanha da Gama 1994). Placing bounds on α allows the estimation of bounds on Nusselt number. On the alternative model there is an indeterminate error involved. Ochoa-Tapia and Whitaker (1995) developed a stress jump boundary condition which, for the case of unidirectional flow, is not greatly different from the Beavers-Joseph condition.

Experimental data sufficient to distinguish between the models is not available.

Address reprint requests to Prof. D. A. Nield, Department of Engineering Science, University of Auckland, Private Bag 92019, Auckland, New Zealand.

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