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European Journal of Mechanics B/Fluids 22 (2003) 545–553
EUROPEAN JOURNAL OF MECHANICS B/FLUIDS

Natural convection in a vertical strip immersed in a porous medium

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Received 17 February 2003; received in revised form 18 July 2003; accepted 18 August 2003

Abstract

In this work, the conjugated heat transfer characteristics of a thin vertical strip of finite length, placed in a porous medium has been studied using numerical and asymptotic techniques. The nondimensional temperature distribution in the strip and the reduced Nusselt number at the top of the strip are obtained as a function of the thermal penetration parameter s, which measures the thermal region where the temperature of the strip decays to the ambient temperature of the surrounding fluid. The numerical values of this nondimensional parameter permits to classify the different physical regimes, showing different solutions: a thermally long behaviour, an intermediate transition and a short strip limit.

Keywords: Porous medium; Natural convection; Heat transfer

1. Introduction

In this work we deal with the problem of the coupled conjugate conduction-natural convective heat transfer in a vertical solid strip totally embedded in a porous medium. The book by Pop and Ingham [1] presents abundant theoretical evidence, showing the importance of the thermal interaction with different heat transfer mechanisms in practical systems. In the same direction, the book of Sundén and Heggs [2] shows that this simple geometrical configuration is found in a broad range of scientific and engineering problems associated with different industrial applications. Additional examples on this and other related topics can be obtained in the books by Ingham and Pop [3], Nield and Bejan [4] and Vafai [5]. Lock and Gunn [6] did the first theoretical study dealing with the conjugate conduction-free convection problem of a long vertical thin strip or fin embedded in a porous medium. They obtained self-similar solutions for the vertical fin geometry. Cheng and Minkowycz [7], Kuehn et al. [8] and Sparrow and Acharya [9] developed equivalent analyses for the same type of problems. Based on these studies, Pop et al. [10] obtained a set of similarity solutions for a long vertical plate projecting downward from a heated horizontal plane base at uniform temperature, for the case of the thermal conductivity-fin thickness product varying as a power of distance from a certain specified origin. Later, Pop et al. [11], improved the above analysis by developing a finite-difference numerical scheme for the case of uniform thickness and thermal conductivity of the fin. Pop and Nakayama [12] reviewed the problem of conjugate convective heat transfer from a vertical fin embedded in a fluid-saturated porous media.

The above mentioned authors mainly consider an infinitely long fin in order to formulate the thermally coupled governing equations. For instance, Pop and Nakayama [12] introduced an unknown characteristic length x_b (Eq. (14) in [12]) in order to nondimensionalize the governing equations and selected an appropriate origin of coordinates. However, the physical interpretation to choose this length scale was not enough clarified. One of the objectives of the present work is to show that this length scale, called in this paper L^*, can be easily estimated using an order of magnitude analysis of the governing equations. Furthermore, we avoid the unnecessary condition to assume an infinitely long fin by considering a vertical strip or fin of finite

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0997-7546/$ – see front matter
doi:10.1016/j.euromechflu.2003.08.003