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Unsteady MHD Non-Darcian Flow Over a Vertical Stretching Plate Embedded in a Porous Medium with Thermal Non-Equilibrium Model

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Abstract. An analysis is performed to study the influence of local thermal non-equilibrium (LTNE) on unsteady MHD laminar boundary layer flow of viscous, incompressible fluid over a vertical stretching plate embedded in a sparsely packed porous medium in the presence of heat generation/absorption. The flow in the porous medium is governed by Brinkman-Forchheimer extended Darcy model. A uniform heat source or sink is presented in the solid phase. By applying similarity analysis, the governing partial differential equations are transformed into a set of time dependent non-linear coupled ordinary differential equations and they are solved numerically by Runge-Kutta Fehlberg method along with shooting technique. The obtained results are displayed graphically to illustrate the influence of different physical parameters on the velocity, temperature profile and heat transfer rate for both fluid and solid phases. Moreover, the numerical results obtained in this study are compared with the existing literature in the case of LTE and found that they are in good agreement.

AMS subject classifications: 76D10, 76S05, 76W05

Key words: MHD, Brinkman-Forchheimer model, heat generation, local thermal non-equilibrium (LTNE).

1 Introduction

The transport in porous media is a process that finds application in a broad spectrum of disciplines ranging from chemical engineering to geophysics. For instance, applications

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of the porous media includes, heat exchangers, geothermal systems, building thermal insulation, nuclear waste disposal, thermal energy storage cooling of nuclear reactors during emergency shutdown etc. to name just few. To be more specific, it may be pointed out that many metallurgical processes involve the cooling of continuous strips or filaments by drawing them through a quiescent fluid and that in the process of drawing, these strips are sometimes stretched. For example in the case of drawing, annealing and tinning of copper wires, the properties of the final product depend to a great extent on the rate of cooling. By drawing such strips in a porous medium [1] and by applying magnetic field, the rate of cooling can be controlled and a final product of desired characteristics can be achieved. Reviews of the huge volume of information on this subject is amply documented in the recent books by Nield and Bejan [2], Vafai [3] and Ingham and Pop [4].

Most of the earlier studies on flow through porous media have been employed with the Darcy model. But in many applications in engineering disciplines involve high permeability porous media. In such situation, Darcy equation fails to give satisfactory results. Therefore, use of non-Darcy models, which takes care of boundary and/or inertia effects, is of fundamental and practical interest to obtain accurate results for high permeability porous media. The inertial and the solid boundary effects on momentum and energy transport have been discussed through constant-porosity media [5] and through non-uniform porosity media [6]. These investigations provided an insight on the applicability of the customarily employed Darcy's law. Due to the importance of non-Darcian effects in the emerging industrial and engineering applications, several researchers [7–11] have analyzed the boundary layer flow characteristics by assuming non-Darcian model.

Most of the analytical and numerical studies of flow and heat transfer in porous media assume the condition of local thermal equilibrium (LTE) between the solid and the fluid materials, i.e., it is assumed that the temperature difference at any location between the two phases is absent. This assumption is satisfactory for small-pore media such as geothermal reservoirs and fibrous insulations and small temperature difference between the phases. But for many practical applications, involving high-speed flows or large temperature difference between the fluid and solid phases, the assumption of local thermal equilibrium is inadequate and it is important to take account of the thermal non-equilibrium effects. Furthermore, when the length scale of the representative control volume is the same order of the length of the system, then the thermal equilibrium model prediction may be unacceptable [12]. Due to applications of porous media theory in drying/freezing of foods [13,14] and othermundane materials and applications in everyday technology such as microwave heating [15], rapid heat transfer from computer chips via use of porous metal foams [16,17] and their use in heat pipes, it is believed that the local thermal non-equilibrium (LTNE) theory will play a major role in future developments.

Reasonably a good number of papers have been focused on impact of LTNE state on convective flow in connection with horizontal cylinder [18], cavity [19,20] and channel [21,22]. In recent years, the effect of local thermal non-equilibrium on natural convection over a vertical plate has been studied by several authors. Much of this study has