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A boundary layer analysis of heat transfer by free convection from permeable horizontal cylinders of elliptic cross-section in porous media using a thermal non-equilibrium model☆

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Abstract

This work uses a thermal non-equilibrium model to study the free convection boundary layer flow driven by temperature gradients near a permeable horizontal cylinder of elliptic cross-section with constant wall temperature in a fluid-saturated porous medium. A coordinate transformation is used to obtain the nonsimilar boundary layer equations. The transformed boundary layer equations are then solved by the cubic spline collocation method. Results for the local Nusselt numbers are presented as functions of the porosity scaled thermal conductivity ratio, the heat transfer coefficient between solid and fluid phases, the transpiration parameter, and the aspect ratio when the major axis of the elliptical cylinder is vertical (slender orientation) and horizontal (blunt orientation). An increase in the porosity scaled thermal conductivity ratio or the heat transfer coefficient between the solid and fluid phases increases the heat transfer rates. Moreover, the use of suction (positive transpiration parameter) tends to increase the heat transfer rates between the porous medium and the surface.

Keywords: Thermal non-equilibrium model; Elliptical cylinder; Porous medium; Cubic spline collocation method; Free convection; Permeable

1. Introduction

The problems of heat and mass transfer around a horizontal cylinder driven by buoyancy forces in a fluid-saturated porous medium is of great importance in geophysical, geothermal and industrial applications, such as the extraction of geothermal energy and the migration of moisture through air contained in fibrous insulations. Merkin [1] presented a similarity solution for natural convection heat transfer on a horizontal cylinder in a saturated porous medium. Pop et al. [2] studied the natural convection heat transfer about cylinders of elliptic cross-section in a porous medium. Yih [3] studied the coupled heat and mass transfer from a permeable horizontal cylinder in a fluid-saturated porous medium. Bradean et al. [4] studied the unsteady free convection adjacent to an impulsively heated horizontal circular cylinder in porous media. Chamkha and Quadri [5] studied the heat and mass transfer from a permeable cylinder in a porous medium with magnetic field and heat generation or absorption effects. Cheng [6]

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examined the coupled heat and mass transfer from a horizontal cylinder of elliptic cross-section in a fluid-saturated porous medium.

The thermal non-equilibrium model is used to account for the temperature difference between solid and fluid phases within the representative control volume in porous media. Jiang et al. [7] presented the numerical simulation for forced convection heat transfer in porous plate channels using thermal-equilibrium and nonthermal equilibrium models. Rees and Pop [8] studied the vertical natural convection boundary layer flow in a porous medium using a thermal non-equilibrium model. Mohamad [9] studied the natural convection in a differentially heated cavity filled with a saturated porous matrix. Baytas and Pop [10] used a thermal non-equilibrium model to study the natural convection flow in a square porous cavity. Al-Amiri [11] studied the problem of natural convection in porous enclosures by the two-energy equation model. Saeid [12] used a thermal non-equilibrium model to study the natural convection near a horizontal cylinder in a porous medium.

This article tends to extend the work of Saeid [12] to include the eccentricity effects and the transpiration effects using the thermal non-equilibrium model. The coordinate transformation and the cubic spline collocation method are applied to study the heat transfer by free convection along a permeable horizontal elliptical cylinder in fluid-saturated porous media with constant wall temperature using a thermal non-equilibrium model. The influence of the transpiration parameter, the porosity scaled thermal conductivity ratio, the heat transfer coefficient parameter, and the aspect ratio on the heat transfer characteristics near a permeable horizontal elliptical cylinder in a fluid-saturated porous medium is examined in both cases when the major axis is horizontal (blunt orientation) and vertical (slender orientation).

2. Analysis

We consider the steady laminar free convection boundary layer flow driven by temperature gradients near a permeable horizontal cylinder of elliptic cross-section embedded in a homogeneous fluid-saturated porous medium in thermal non-equilibrium. The coordinate system for the elliptical cylinder with blunt orientation is shown in Fig. 1, where a is the length of semi-major axis, b is the length of semi-minor axis, A represents the angle made by the outward normal from the cylinder with the downward vertical, and B is the eccentric angle. For cylinders of elliptic cross-section there are two orientations to consider: the orientation is blunt when the major axis is horizontal, as shown in Fig. 1, and the orientation is slender when the major axis is vertical.

The surface of the cylinder is maintained at a constant temperature T_w which is higher than the ambient fluid temperature T_∞. It is assumed that the fluid properties are assumed to be constant except for density variations in the buoyancy force term. The viscous drag and inertial terms are neglected. Using the thermal non-

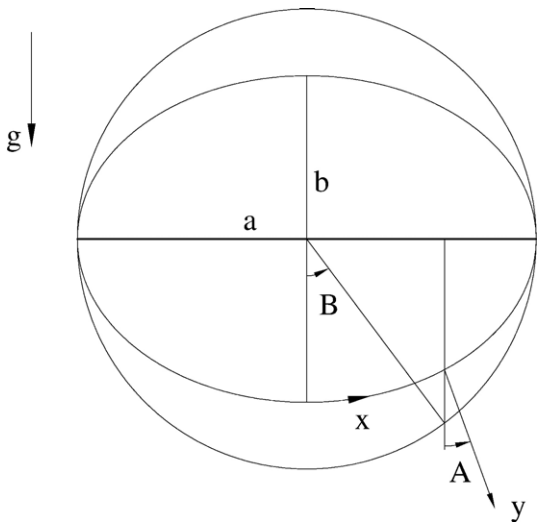

Fig. 1. Physical model and coordinates for an elliptic cylinder of blunt orientation.