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Natural convection flow along a vertical wavy surface with the effect of viscous dissipation and magnetic field in presence of Joule heating

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Abstract

The combined effect of viscous dissipation and Joule heating on magneto-hydrodynamic (MHD) natural convection flow along a uniformly heated vertical wavy surface has been investigated in this paper. Using a set of appropriate transformation the governing boundary layer equations are converted into dimensionless non-similar equations and solved numerically by the finite difference method, known as Keller-Box scheme. Numerical solutions are obtained for velocity, temperature, local skin friction and Nusselt number which are shown graphically in figures along for the wavy surface for a selection of parameter sets consisting of Joule heating parameter, Eckert number, Pradtl number and MHD parameter. Numerical results show that these parameters have significant influences on the velocity and temperature as well as for the local friction and Nusselt number.

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Keywords: Joule heating; MHD; Viscous dissipation; Natural convection; Wavy surface

1. Introduction

The viscous dissipation effect plays an important role in natural convection in various devices which are subjected to large deceleration or which operate at high rotational speeds and also in strong gravitational field processes on large scales(on large planets), in geological process and in nuclear engineering in connection with the cooling of reactors. Along with the natural convection flow the phenomenon of the boundary layer flow of an electrically conducting fluid in the presence of Joule heating and magnetic field are also very common because of their applications in nuclear engineering in connection with the cooling of reactors. Natural convection flow is often encountered in cooling of nuclear reactors or in the study of the structure of stars and planets. The study of temperature and heat transfer is of great importance to the engineers because of its almost universal occurrence in many branches of science and engineering. It is also necessary to study the heat transfer from an irregular surface because irregular surfaces are often present in many applications, such as radiator, heat exchangers and heat transfer enhancement devices. Yao [1] first investigated the natural convection heat transfer from an isothermal vertical wavy surface and used an extended Prantdl?s transposition theorem and a finite-difference scheme. Natural convection flow along a vertical wavy surface with uniform surface temperature in presence of heat generation/absorption presented by Molla et al. [2]. Alam et al. [3] studied numerical viscous dissipation effects on MHD natural convection flow over a sphere in the presence of heat generation. Devi and Kayalvizhi [4] investigated viscous dissipation and radiation effects on the thermal boundary layer flow with heat and mass transfer over a non-isothermal stretching sheet with internal heat generation embedded

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in a porous medium. Jha and Ajibade [5] analyzed effect of viscous dissipation on natural convection flow between vertical parallel plates with time-periodic boundary conditions. Recently, Parveen et al. [6] investigated viscous dissipation effect on natural convection flow along a vertical wavy surface. The discussion and analysis of natural convection flows, viscous dissipation, Joule heating and magnetic field effect are generally ignored but here we have considered the effect of viscous dissipation, Joule heating and magnetic field on natural convection flow of a viscous incompressible fluid along a vertical wavy surface. The surface shear stress in terms of local skin friction coefficient and the rate of heat transfer in terms of local Nusselt number, the streamlines as well as the isotherms patterns are shown graphically for the effect of varying the Eckert number Ec and the Joule heating parameter J.

2. 2. Mathematical formulation of the problem

The boundary layer analysis outlined below allows $\bar{\sigma}$(X) being arbitrary, but our detailed numerical work assumed that the surface exhibits sinusoidal deformations. The wavy surface may be described by

$$Y_w = \bar{\sigma}(X) = \alpha sin(\frac{n\pi X}{L}) \tag{1}$$

where L is the wave length associated with the wavy surface.
The geometry of the wavy surface and the two-dimensional cartesian coordinate system are shown in Fig. 1.

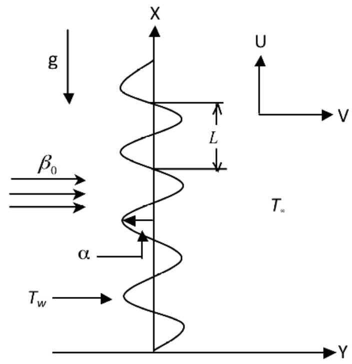

Fig. 1: Physical model and coordinate system

Under the usual Boussinesq approximation, the governing equations describing the conservation of mass, momentum and energy, respectively can be written non dimensional form as follows:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{2}$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial v}{\partial y} = -\frac{\partial p}{\partial x} + Gr^{\frac{1}{4}}\sigma_x\frac{\partial p}{\partial y} + (1+\sigma_x^2)\frac{\partial^2 u}{\partial y^2} - Mu + \theta \tag{3}$$

$$\sigma_x(u\frac{\partial u}{\partial x} + v\frac{\partial v}{\partial y}) = -Gr^{\frac{1}{4}}\frac{\partial p}{\partial y} + \sigma_x(1+\sigma_x^2)\frac{\partial^2 u}{\partial y^2} - \sigma_{xx}u^2 \tag{4}$$

$$u\frac{\partial \theta}{\partial x} + v\frac{\partial \theta}{\partial y} = \frac{1}{P_r}(1+\sigma_x^2)\frac{\partial^2 \theta}{\partial y^2} + Ec(\frac{\partial u}{\partial y})^2 + Ju^2 \tag{5}$$

In the above equations P_r, Ec, J and M are respectively known as the Prandtl number, Eckert number, Joule heating parameter and magnetic parameter, which are defined as

$$P_r = \frac{C_p\mu}{k}; Ec = \frac{\nu^2 G_r}{L^2 C_p(T_w - T_\infty)}; J = \frac{\sigma_0\beta_0^2\nu G_r^{\frac{1}{2}}}{\rho C_p(T_w - T_\infty)}; M = \frac{\sigma_0\beta_0^2 L^2}{\mu G_r^{\frac{1}{2}}}$$