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REVIEW

Effect of internal heat generation or absorption on MHD free convection from an isothermal truncated cone

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Abstract This paper examines the effect of heat generation or absorption on the free convection flow of an incompressible, electrically conducting fluid about an isothermal truncated cone in the presence of a transverse magnetic field. The non-linear coupled partial differential equations governing the flow and heat transfer have been solved numerically, using an efficient implicit finite-difference scheme along with quasilinearization technique. The nonsimilar solutions have been obtained for the problem overcoming numerical difficulties near the leading edge and in the downstream regime, for air ($Pr = 0.72$). The effects of various physical parameters on skin friction and heat transfer coefficients and, on velocity and temperature are shown graphically for different values of magnetic parameter (M) and heat generation/absorption parameter (Q). It is observed that, magnetic field decreases both skin friction and heat transfer coefficients. The effect of heat generation or absorption is found to be very significant on heat transfer, but its effect on skin friction is negligible.

Contents

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1. Introduction

The problem of natural convection flow over the frustum of a cone without the transverse curvature effect (i.e., large cone angles when the boundary layer thickness is small compared to the local radius of the cone) has been treated by Na [1] for an isothermal surface. Hering and Grosh [2] studied the laminar natural convection from a non-isothermal cone and showed that similarity solutions exist when the cone wall temperature varies as a power of distance along a cone ray. Later, Hering [3] extended the analysis to investigate the flow for low Prandtl number fluids. Roy [4] extended the study of Hering and Grosh [2] to treat the case for fluids having high Prandtl numbers. Alamgir [5] used an integral method to study the overall heat transfer from vertical cones in laminar natural convection.

There has been a great interest in the study of magneto hydrodynamic (MHD) flow and heat transfer in any medium due to the effect of magnetic field on the boundary layer flow control and on the performance of many systems using electrically conducting fluids. This type of flow has attracted the interest of many researchers [6–14] due to its applications in many engineering problems such as MHD generators, plasma studies, nuclear reactors, and geothermal energy extractions.

A large number of physical phenomena involve natural convection driven by heat generation. The study of heat generation (or absorption) in moving fluids is important in several physical problems dealing with chemical reactions and those concerned with dissociating fluids. Possible heat generation effects may alter the temperature distribution and therefore, the particle deposition rate. In addition, understanding the effects of internal heat generation is also significant in numerous applications that include reactor safety analysis, metal waste, spent nuclear fuel, fire and combustion studies and strength of radioactive materials.

The effect of heat generation/absorption on free convective flows has been studied by several authors [15–19] and, motivated by these works; the present work aimed to study the effect of internal heat generation or absorption on free convection flow of an incompressible, electrically conducting fluid from an isothermal truncated cone in the presence of an applied magnetic field.

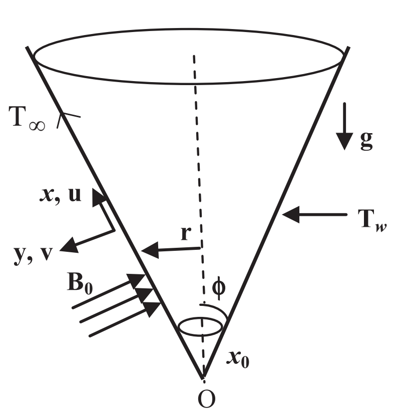

Figure 1 The flow geometry and the coordinate system.

2. Mathematical model

We consider the steady, two-dimensional laminar natural convection flow of a viscous incompressible fluid about an isothermal truncated cone in the presence of internal heat generation or absorption. Fig. 1 shows the flow model and physical coordinate system. The origin of the coordinate system is placed at the vertex of the full cone, where x is the coordinate along the surface of the cone measured from the origin, and y is the coordinate normal to the surface. It is assumed that the boundary layer to be sufficiently thin in comparison with the local radius of the truncated cone. The local radius to a point in the boundary layer can be replaced by the radius of the truncated cone r, $r = x\sin\phi$, where ϕ is semi vertical angle of the cone.

A transverse magnetic field of strength $B_0(x)$ is applied in the direction normal to the surface of the isothermal truncated cone and it is assumed that magnetic Reynolds number is small, so that the induced magnetic field can be neglected. The boundary layer is assumed to develop at the leading edge of the truncated cone ($x = x_0$) which implies that the temperature at the circular base is assumed to be the same as the ambient temperature T_∞. The temperature of the surface of the cone T_w is uniform and higher than the free stream temperature T_∞ ($T_w > T_\infty$).

Under the above assumptions, the two-dimensional MHD boundary layer equations for natural convective flow of the electrically conducting fluid over a isothermal truncated cone, valid in the domain $x_0 \leqslant x \leqslant \infty$, are the continuity, momentum and energy equations, respectively given by

$$\frac{\partial(ru)}{\partial x} + \frac{\partial(rv)}{\partial y} = 0 \tag{1}$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \frac{1}{\rho}\frac{\partial}{\partial y}\left(\mu\frac{\partial u}{\partial y}\right) + g\beta\cos\varphi(T - T_\infty) - \frac{\sigma B_0^2(x)}{\rho}u \tag{2}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} + \frac{Q_0}{\rho c_p}(T - T_\infty) \tag{3}$$

where u, v are the components of velocity respectively in x- and y-directions, g the gravitational acceleration, μ coefficient of fluid viscosity, β the coefficient of thermal expansion, T the temperature inside the boundary layer, α the thermal diffusivity, ρ the density of the fluid, c_p the specific heat, and Q_0 is the heat generation or absorption coefficient.

2.1. Boundary conditions

The appropriate boundary conditions for the problem are given by