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Unsteady Boundary Layer Flow Induced by a Stretching Sheet in a Rotating Fluid with Thermal Radiation

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Abstract

The MHD unsteady flow heat and mass transfer of a viscous incompressible fluid induced by a stretching surface in a rotating fluid taking the effects of thermal radiation, heat absorption and first order chemical reaction into account with convective boundary condition. The rotation parameter is found to reduce the velocities and the magnetic parameter prevents the flow reversal in the x – direction. The increasing values of Biot number generate thicker thermal boundary layers resulting in the rise of temperature. The Schmidt number and chemical reaction parameter are found to have a strong influence on the species concentration resulting in small values. The rate of heat transfer is enhanced by magnetic field, thermal radiation parameter and rotation parameter. The rotation parameter and time are observed to enhance the rate of mass transfer.

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Keywords: MHD; Unsteady boundary layers; Rotating flows; Convective boundary condition

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1. Introduction

The study of fluid flow over a stretching surface in a rotating fluid finds application to study the geological stretching of a techtonic surface in a rotating ocean (Wang [1]). Gorla et al. [2] discussed the steady flow of an incompressible power law fluid past a horizontal stretching plate that rotates around vertical axes. Takhar and Nath [3] analysed the effect of the magnetic field on the unsteady flow and heat transfer of a viscous incompressible electrically conducting fluid due to a stretching surface in a rotating fluid. Takhar et al. [4] analysed the steady flow

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and heat transfer on a stretching surface in a rotating fluid subject to a magnetic field. Nazar et al. [5] studied the flow due to a suddenly stretching surface in a rotating fluid.

Thermal radiation plays a significant role in manufacturing process in industry. For example, in casting and levitation, metallic rolling, design of furnace, fins. In engineering, many processes involve very high temperatures and the application of radiative heat transfer is essentially required to design the specific equipment. Nuclear power plants, gas turbines, satellites and space vehicles are some of the examples (Seddeek [6]) which involve radiative heat transfer.

In this paper an effort is made to investigate the effect of thermal radiation on the unsteady flow of a viscous, incompressible, electrically-conducting fluid caused by the stretching of a surface in a rotating fluid to know the influence of thermal radiation, magnetic field, chemical reaction and heat sink.

2. Mathematical Formulation

Let us consider the unsteady motion of a viscous incompressible electrically conducting fluid induced by the stretching of a surface in the x – direction in a rotating fluid. The rotation of the fluid makes the flow three-dimensional.

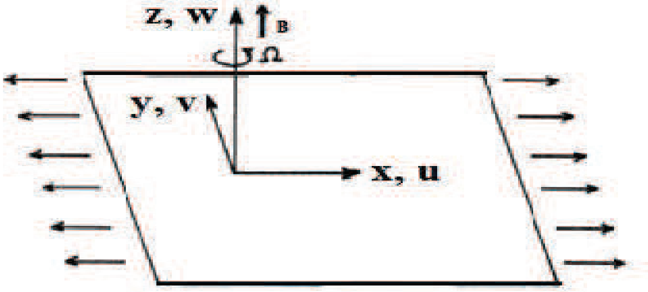

Fig. 1 Physical model and coordinate system

Fig. 1 shows the coordinate system, where u, v and w be the velocity components in the x, y and z respectively. A uniform magnetic field **B** is applied in the z – direction. The velocity components u, v and w, temperature T and concentration C depend only on x and z as the flow is induced by stretching the surface in the x – direction only. The induced magnetic field is neglected by assuming that the magnetic Reynolds number is small. The surface temperature and the fluid temperature at the edge of the boundary layer are all assumed to be constant. Initially (i.e. at $t^* = 0$) the stretching surface varies linearly at a distance from leading edge (i.e. $u_w = ax, a > 0$) and the fluid is rotating with an angular velocity Ω_0. At $t^* > 0$, the velocity of stretching surface is taken as $u_w = ax$ $(1 - \alpha t^*)^{-1}$and the fluid is rotating with an angular velocity $\Omega = \Omega_0(1 - \alpha t^*)^{-1}$ about z – axis.

Under these assumptions, the equations of continuity, motion, heat and mass transfer can be written as

$$u_x + v_y + w_z = 0 \tag{1}$$

$$u_t + uu_x + vu_y + wu_z - 2\Omega v = -\rho^{-1}p_x + \nu\,\nabla^2 u - \sigma\rho^{-1}B^2 u \tag{2}$$

$$v_t + uv_x + vv_y + wv_z - 2\Omega u = -\rho^{-1}p_y + \nu\,\nabla^2 v - \sigma\rho^{-1}B^2 v \tag{3}$$

$$w_t + uw_x + vw_y + ww_z = -\rho^{-1}p_z + \nu\,\nabla^2 w \tag{4}$$

$$T_t + uT_x + vT_y + wT_z = \frac{1}{\rho c_p}\left[K\nabla^2 T - \frac{\partial q_r}{\partial z} - Q^*(T - T_\infty)\right] \tag{5}$$

$$C_t + uC_x + vC_y + wC_z = D\nabla^2 C - k(C - C_\infty) \tag{6}$$

Where $\nabla^2 = \left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}\right)$.

The boundary conditions are

$u(x, y, 0, t^*) = u_w,\ v(x, y, 0, t^*) = w(x, y, 0, t^*) = 0,\ -k_f\frac{\partial T}{\partial z} = h_f(T_w - T),\ C(x, y, 0, t^*) = C_w,$

$p(x, y, 0, t^*) = p_w$