HALL RESULTS ON UNCONTROLLED NATURAL CONVEC TIVE FLOW OF MHD THROUGH AN IMPULSIVELY FLO WING PLATE WITH TEMPERATURE AND CONCENTRAT ION RAMPED

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ABSTRACT

In this paper, we discuss heat transfer on the peristaltic magneto hydrodynamic flow of a Jeffrey fluid through a porous medium in a vertical echelon under the influence of a uniform transverse magnetic field normal to the channel, taking Hall current into account. This study is motivated towards the physical flow of blood in a microcirculatory system by taking account of the particle size effect. Here we consider the Reynolds number to be small enough and wavelength-to-diameter ratio large enough to neglect inertial effects. The nonlinear governing equations for the Jeffrey fluid are solved making use of the perturbation technique. The exact solutions for the velocity, temperature, and the pressure rise per one wavelength are determined analytically. Its behavior is discussed computationally with reference to different physical parameters. Some parameters are the strongest on the trapping bolus phenomenon and the pumping characteristics. The size of the trapping bolus decreases with increasing Hartmann number or permeability parameter and increases with increasing Hall parameter or Jeffrey number.

I Introduction

The Hall effect principle was discovered by an American physicist named Edwin Hall in 1879. The topic of Hall effect in magneto hydrodynamics is a recent trend because of its important influence of the electromagnetic force. The Hall effect parameter is defined as the ratio between the electron-cyclotron frequency and the electron-atomcollision frequency. The principle of Hall effect is used to determine the efficiency of some devices such as power generators and heat exchangers. Hayat et al. [1]studied the hall effects on peristaltic flow of a Maxwell fluid in a porous medium. Eladahab et al. [2] analysed the effects of hall and ion-slip currents on peristaltic transport of a couple stress fluid. The effects due to the hall current become significant when the hall parameter is high. This situation occurs as a result of high magnetic field or low collision frequency. In dealing with weak and moderate magneticfields, the Hall effect is ignored and the results give good agreement with experimental data. Further Eldahab [3] studied Hall currents and ion-slip effects on the MHD peristaltic transport. Some studies pertaining to the peristaltic transport with Hall effect are mentioned in Refs[4–6]. Therefore, Hall currents are important and they have remarkable effects on the magnitude and the direction of the current density and consequently on the magnetic force term. These facts make the impact of Hall current on the flow worth studying. The heat transfer analysis plays a significant role because it provides us information about the blood flow rate. Heat transfer takes place in the human body by conduction, convection, evaporation and radiation. Bioheat transfer finds applications in laser therapy, cryosurgery, cancer tumour treatment and hypothermia. The study of heat transfer in peristaltic flows is important in some biomedical processes like hemodialysis and oxygenation. The effects of Hall and heat transfer are likely to be important in many situations as well as in engineering applications in areas like power generators, MHD and Hall accelerators, electric transformers, refrigeration coils and heating elements.Srinivas and Kothandapani[7] analysed the Hall currents and heat transfer effects on peristaltic transport through a porous medium. Prabhakar Reddy[8] studied the MHD flow over a vertical moving porous plate with viscous dissipation by considering double diffusive convection in the presence of chemical reaction. The topic of Hemodynamics or blood flow problems have received a great attention due to its application in physiopathology. The analysis of blood flow in peristalsis has caught the attention of many physiologists. Basically peristaltic mechanism consists of expansion and contraction activities which propel the material forward. Some examples of peristaltic phenomenon include transport of urine from kidney to gallbladder, transport of bile in the bile duct, transport of cilia, mixing of food in digestive tract, vasomotion of small blood vessels etc. This process has many industrial applications such as rollers, hose and tube pumps whereas peristaltic pumps used in dialysis, open-heart by pass and heart-lung machines are few biomedical applications. Latham [9] was the first to examine the peristaltic motion of fluid in a pump. Later, Shapiro et.al [10] examined the peristaltic flow with long wavelength and low Reynolds number assumptions Some studies relating to the peristaltic flow of Newtonian and non-Newtonian fluids are given in Refs [11–13],Hayman and Subhash[14]

2 Formulation of the Problem

Consider the unsteady hydromagnetic flow of a viscous incompressible electrically conducting and heat radiating fluid past an impulsively moving infinite vertical plate with ramped plate temperature and mass transfer where a uniform magnetic field B r of strength B0 is applied in the direction perpendicular to the fluid flow. Choose a Cartesian co-ordinate system with the x - axis along the plate in the vertically upward direction, the y - axis perpendicular to the plate and z - axis is the normal of the xy -plane. The physical model of the problem is presented in Fig. 1. Initially, at time $t \leq 0$, the plate and the fluid are at rest at a uniform temperature T∞ and species concentration C∞ .

$$T_w + (T_w - T_\infty)\frac{t}{t_0}, \ T_w \neq T_\infty$$

At time t> 0 , the plate at y = 0 starts to move in its own plane with a uniform velocity 0 u and the temperature of the plate at y = 0 is raised or lowered to 0 ( ) and also the mass concentration at the plate y = 0 effects of the convective and pressure gradient terms in the momentum and energy equations can be neglected. It is also assumed that the radiative heat flux in the x - direction is negligible as compared to that in the y - direction. As the plate is of infinite extent and electrically nonconducting, all physical quantities, except the pressure, are functions of y and t only. Generalized Ohm's law on taking Hall current into account is (Cowling20):

$$\vec{J} + \frac{\omega_e \tau_e}{B_0}\left(\vec{J} \times \vec{B}\right) = \sigma\left(\vec{E} + \vec{q} \times \vec{B}\right), \qquad \ldots (1)$$

In view of the above assumption, Eq. (1) yields:

$$j_x - m j_z = \sigma(E_x - wB_0), \qquad \ldots (2)$$

$$j_z + m j_x = \sigma(E_z + uB_0), \qquad \ldots (3)$$

where m = ωe τe is the Hall parameter which represets the ratio of electron-cyclotron frequency and the electron-atom collision frequency. In general, Hall currents influence the mechanics of a flow system when applied magnetic field is strong or when the collision frequency is low .The effect of Hall currents gives rise to a force in the y -direction, which induces a cross flow in that direction. To simplify the problem, we assume that there is no variation of flow quantities in y -direction. This assumption is considered to be valid if the surface be of infinite extent in the y - direction.

Solving for jx and jZ from (2) and (3), on taking 0 Ex = Ez =0 , we have:

$$j_x = \frac{\sigma B_0}{1+m^2}(mu - w), \qquad \ldots (4)$$

$$j_z = \frac{\sigma B_0}{1+m^2}(mw + u). \qquad \ldots (5)$$

Taking into consideration the assumptions made above, the governing equations for laminar natural convection flow of a viscous incompressible and electrically conducting fluid with radiative heat transfer, under Boussinesq approximation, i.e. the density changes with temperature, which gives rise to the buoyancy force.

2.1 Solution when Prandtl number is unity

In the absence of thermal radiation (i.e. when R → ∞), i.e. if pure convection prevails, it is observed that α = Pr and the solution for the temperature given by Eq. (31) is valid for all values of Pr , but the solution for the velocity field given by Eq. (33) is not valid for Pr 1 = . Since the Prandtl number is a measure of the relative importance of the viscosity and thermal conductivity of the fluid, the case Pr 1 = corresponds to those fluids whose momentum and thermal boundary layer thicknesses are of the same order of magnitude. Therefore, the solution for the velocity field in the absence of thermal radiation effects when Pr 1 = has to be obtained subject to the initial and boundary conditions (22). It can be expressed in the following form:

$$F(\eta,\tau) = \begin{cases} f_2(\eta,\tau) + \dfrac{\mathrm{Gr}}{\mathrm{Pr}-1}\Big[f_3(\eta,\beta_0,\tau) - f_4(\eta\sqrt{\mathrm{Pr}},\beta_0,\tau) \\ -H(\tau-1)\{ f_3(\eta,\beta_0,\tau-1) - f_4(\eta\sqrt{\mathrm{Pr}},\beta_0,\tau-1)\}\Big] \\ -\dfrac{\mathrm{Gc}}{a^2}\big[f_5(\eta,a,\tau) - f_1(\eta,\tau) \\ -H(\tau-1)\{ f_5(\eta,a,\tau-1) - f_1(\eta,\tau-1)\}\big] \quad \text{for } Pr \neq 1,\ Sc = 1 \\ \\ f_2(\eta,\tau) - \dfrac{\mathrm{Gr}+\mathrm{Gc}}{a^2}\big[f_5(\eta,a,\tau) - f_1(\eta,\tau) \\ -H(\tau-1)\{ f_5(\eta,a,\tau-1) - f_1(\eta,\tau-1)\}\big] \quad \text{for } Pr = 1,\ Sc = 1 \end{cases}$$

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where 1 f , 2 f , 3 f , 4 f and 5 f are dummy functions which are given in Appendix A. 2.2 Solution for isothermal plate or constant plate temperature In order to highlight the effect of the ramped boundary conditions on the flow, it may be worthwhile to compare such a flow past a moving plate with constant temperature. In this case, the initial and boundary conditions (22) are the same excepting the condition θ (0, τ) =1 and φ (0, τ) =1 for τ ≥ 0 . Under the assumptions, it can be easily shown that the concentration, temperature and velocity fields for the flow past a moving plate with constant temperature can be expressed as:.

$$\varphi(\eta,\tau) = \operatorname{erfc}\left(\frac{\eta}{2}\sqrt{\frac{\alpha}{\tau}}\right), \qquad \ldots\ldots 6$$

$$F(\eta,\tau) = f_2(\eta,\tau) + \frac{\mathrm{Gr}}{\alpha-1}\left[f_6(\eta,\beta_0,\tau) - f_7(\eta\sqrt{\alpha},\tau)\right] + \frac{\mathrm{Gc}}{\mathrm{Sc}-1}\left[f_6(\eta,\gamma,\tau) - f_7(\eta\sqrt{\mathrm{Sc}},\tau)\right] \text{for } \alpha \neq 1,\ Sc \neq 1, \qquad \ldots\ldots 7$$

3 Results and Discussion

In this section, the obtained exact solutions are studied in order to determine the effects of embedded parameters. Numerical values of the non-dimensional fluid velocity components u1 and w1 , fluid temperature θ , concentration φ for several values of magnetic parameter M2 , Hall parameter m , radiation parameter R , thermal Grashof number Gr , mass Grashof number Gc , Prandtl number

Pr , Schmidt number Sc and time τ. The ghraphical results are presented using Mathematica.

4 Conclusions

In this paper, the impacts of Hall effect, radiation and ramped wall temerature and mass concentration on the unsteady hydro magnetic free convective flow of a viscous incompressible electrically conducting and heat radiating fluid past an infinite vertical plate hasve been examined. The main findings obtained from the present study may be summarized as follows:

(i) The primary and secondary velocities are retarded under the effects of transverse magnetic field whereas these are accelerated due to Hall effects in both ramped temperature and isothermal cases.

(ii) An increase in either radiation parameter or thermal Grashof number or mass Grashof number leads to rise in the velocity components.

(iii) The fluid temperature decreases with an increase in radiation parameter. The fluid temperature increases when time progresses.

(iv) Such a fluid flow finds many engineering applications such as those in MHD devices and in several natural phenomena occurring subject to thermal radiation in the presence of mass transfer.

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