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UNSTEADY MHD FREE CONVECTION COUETTE FLOW BETWEEN TWO VERTICAL PERMEABLE PLATES IN THE PRESENCE OF THERMAL RADIATION USING GALERKIN'S FINITE ELEMENT METHOD

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ABSTRACT

This paper investigates the unsteady magneto hydrodynamic natural convection Couette flow of an incompressible viscous fluid in the presence of thermal radiation. A uniform magnetic field which acts in adirection orthogonal to the permeable plates, and uniform suction and injection through the plates are applied. The magnetic field lines are assumed to be fixed relative to the moving plate. The momentum equation considers buoyancy forces while the energy equation incorporates the effects of thermal radiation. The fluid is considered to be a gray absorbing-emitting but non-scattering medium in the optically thick limit. The Rossel and approximation is used to describe the radiative heat flux in the energy equation. The coupled pair of partial differential equations is discretized using the Galerkin finite element method. The resulting system of equations is solved to obtain the velocity and temperature distributions. The effects of suction parameter S, radiation parameter Rd, Grashof number Gr, magnetic parameter H and Prandtl number Pr on both the velocity and temperature distributions are studied.

KEYWORDS: Couette Flow, Finite Element Method, Free Convection, MHD, Thermal Radiation, Vertical Permeable Channel

INTRODUCTION

The study of magneto hydrodynamics (MHD) is of great importance in many engineering applications such as in the use of MHD pumps in chemical energy technology and in the use of MHD power generators [6]. The steady flow of an electrically conducting fluid between two infinite parallel stationary plates in the presence of a transverse uniform magnetic field was first studied by Hartmann and Lazarus in 1937 [1, 18]. Rossow [18] considered the flow of an electrically conducting fluid over a flat plate in the presence of a transverse magnetic field in the cases where the magnetic field is fixed relative to the plate and fixed relative to the fluid. It was observed that when themagnetic field is considered to be fixed relative to the plate, the flow is accelerated by the magnetic field. However,the magnetic field retards the fluid flow when the magnetic field is fixed relative to the fluid.

The study of MHD Couette flow is important in industrial and engineering applications such as MHD pumps, MHD power generators, polymer technology and electrostatic precipitation [2]. Katagiri (1962) extended the work of Hartmann and Lazarus to the case of unsteady Couette flow [20]. Muhuri (1963) further extended this study by considering the Couette flow in the presence of uniform suction and injection between porous walls when one of the walls is uniformly accelerated [20].

The unsteady MHD Couette flow between two infinite parallel porous plates with uniform suction and injection in the cases of impulsive and uniformly accelerated movement of the lower plate was studied by Seth et al. [19]. The lower plate is at rest in both cases and the magnetic field is fixed with respect to the moving plate. The velocity distribution and the shear stress on the moving plate were obtained using the Laplace transform technique. It was observed that in both cases, increasing the magnetic parameter results in an increase in the velocity, and increasing the suction parameter decreases the velocity.

The study of free convection flow is useful for energy-related engineering applications such as geophysics and problems involving the spread of pollution [15]. Suriano et al. [22] studied free convection flow along an isothermal vertical finite plate using perturbation analysis, and the velocity and temperature fields were obtained for small Grash of number. This problem was extended by Suriano and Kwang-Tzu [23] to include moderate Grash of numbers by using a numerical finite difference scheme. The effect of natural convection on unsteady Couette flow was studied by Singh [20]. The Laplace transform technique was used to obtain the velocity and temperature fields, the skin-friction andrate of heat transfer. It was observed that an increase in the Grash of number results in an increase in the flow velocity. Jha [6] extended the work of Singh [20] by discussing the combined effects of natural convection and a uniform transverse magnetic field when the magnetic field is fixed relative to the plate or fluid. Using the Laplace transform technique, exact solutions were obtained for the velocity and temperature fields. The trends observed with respect to the magnetic field strength were consistent with those observed in [18]. Singh et al. [21] compared the unsteady free convection Couette flow at large values of time with the corresponding steady-state problem and found that they are in good agreement. It was also observed that the flow velocity decreases with increasing Prandtl number. Jha and Apere [7] extended the work of Jha [6] by considering the unsteady MHD free convection Couette flow between two vertical parallel porous plates with uniform suction and injection. The cases where the magnetic field is considered fixed relative to the fluid and fixed relative to the moving plate were considered. The velocity and temperature distributions were obtained using the Laplace transform technique. The results revealed that both temperature and velocity decrease with increasing Prandtl number and with increasing suction/injection parameter. The effect of magnetic field strength on the velocity is consistent with the results obtained in [6] and [18]. The velocity has also been found to increase with increasing Grash of number.

The effects of thermal radiation on fluid flow are industrially important in the study of heat transfer where high temperatures are involved. Thermal radiation effects may be non-negligible in engine combustion chambers, furnaces and power plants for gas cooled nuclear reactors [12]. In the limit of an optically thick medium, the radiative flux is related to the temperature using the Rossel and Approximation [10]. The unsteady MHD free convection flow bounded by an infinite vertical porous plate in the presence of thermal radiation was studied by Perdik is and Rapti [11]. The radiative heat flux was described using the Rossel and approximation, and the temperature and suction velocity at the plate were taken to be time-dependent. The velocity and temperature distributions were obtained using an asymptotic expansion of velocity for small magnetic number, as well as a similarity transformation. The results showed a decrease in both velocity and temperature with increasing radiation and suction parameters. Rajput and Sahu [13] investigated the unsteady natural convection hydromagnetic Couette flow between two infinite vertical plates in the presence of thermal radiation.

The magnetic field is assumed to be fixed relative to the moving plate, and the cases of impulsive and uniformly accelerated movement of the plate are considered. The Rossel and approximation was used to describe the radiative heat flux. The velocity and temperature distributions, the skin-friction and Nusselt number were obtained using the Laplace transform technique. The authors [13] discovered that the velocity and temperature decrease with increasing Prandtl number and with increasing radiation parameter in both cases.

It was also observed that increasing the magnetic parameter increases the velocity in the case of impulsive movement of the plate but decreases the velocity in the case of uniformly accelerated movement of the plate. Increasing the Grash of number results in an increase in the velocity in both cases. Rajput and Sahu [14] later extended their work by including the effect of a heat source or heat sink with constant heat flux at one plate. The results obtained are consistent with those obtained in [13].

This paper aims to extend the work of Rajput and Sahu [13] by incorporating the effects of uniform suction and injection through the plates. The problem is solved using Galerkin's finite element method and the effects of suction parameter S, radiation parameter Rd, Grash of number Gr, magnetic parameter H and Prandtl number Pr on both the velocity and temperature distributions are investigated.

MATHEMATICAL ANALYSIS

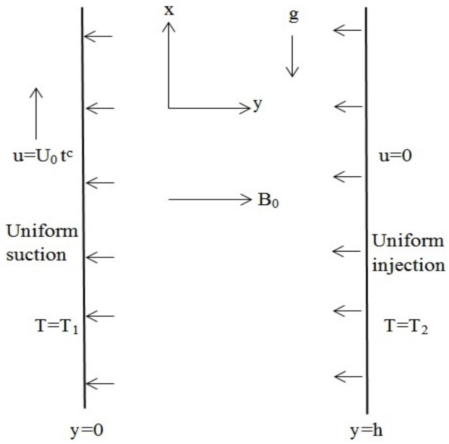

Figure 1: Schematic Diagram of the Physical System

The incompressible Newtonian fluid flows between two parallel vertical non-conducting permeable plates. These plates are located on planes y = 0 and y = h, and are infinite in the x and z directions. The plate at y = h is stationary and the other plate moves with time-dependent velocity U_0t^c in the positive x-direction (where U_0 is constant and cis a non-negative integer). The temperature of the moving and stationary plates are fixed at T_1 and T_2 respectively, with $T_1>T_2$. Uniform suction through the moving plate and uniform injection through the stationary plate are applied through the plates at t = 0 in the negative y direction. A magnetic field with magnitude B_0, which is fixed relative to the moving plate, is applied in the positive y-direction.

We make the following simplifying assumptions.

- The magnetic Reynolds number is very small.
- For a typical conductor, the charge density $\rho_e$is very small; hence it is negligible.
- The Boussinesq approximation is applied.
- The fluid is a gray and optically thick absorbing-emitting but non-scattering medium.
- The fluid has a refractive index of unity.

Under the above assumptions, the governing equations are:

Continuity Equation:

$$\frac{\partial u}{\partial x} = 0 \tag{1}$$

Momentum Equation:

$$\rho\left(\frac{\partial u}{\partial t}-v_o\frac{\partial u}{\partial y}\right)=\rho g\alpha(T-T_2)-\gamma B_0^2(u-U_0t^c)+\mu\frac{\partial^2 u}{\partial y^2}$$

Energy Equation:

$$\rho c_p\left(\frac{\partial T}{\partial t}-v_0\frac{\partial T}{\partial y}\right)=\kappa\frac{\partial^2 T}{\partial y^2}-\frac{\partial q_r}{\partial y} \tag{3}$$

where u is the flow velocity in the x-direction, ρ is the fluid density, v_o is the constant suction/injection velocity , g is the acceleration due to gravity, α is the coefficient of thermal expansion, T is the fluid temperature, γ is the electrical conductivity, μ is the viscosity, c_p is the the specific heat capacity at constant pressure, κ is the thermal conductivity and q_r is the radiative heat flux.

The boundary conditions are:

$$u(y,0)=0,\ u(0,t)=U_0t^c,\ u(h,t)=0 \tag{4}$$

$$T(y,0)=T_2,\ T(0,t)=T_1,\ T(h,t)=T_2 \tag{5}$$

The radiative flux is simplified using the Rosseland approximation to give

$$q_r=-\frac{4\sigma}{3\beta_R}\frac{\partial T^4}{\partial y} \tag{6}$$

whereσ is the Stefan-Boltzmann constant and β_R is the mean absorption coefficient.

Following [13], we assume that the differences in temperature within the flow are sufficiently small such that q_r may be expressed as a linear function of T. Hence, on taking a first order approximation of T^4 in a Taylor series about T_2, we get

$$T^4\cong T_2^4+4(T-T_2)T_2^3=4T_2^3T-3T_2^4$$

Using this approximation in equation (6) gives

$$q_r=-\frac{16\sigma T_2^3}{3\beta_R}\frac{\partial T}{\partial y}$$

which on subtituting into equation (3) gives

$$\rho c_p\left(\frac{\partial T}{\partial t}-v_0\frac{\partial T}{\partial y}\right)=\left(\kappa+\frac{16\sigma T_2^3}{3\beta_R}\right)\frac{\partial^2 T}{\partial y^2} \tag{7}$$

We define the following dimensionless quantities:

$$\hat{x}=\frac{x}{h},\hat{y}=\frac{y}{h},\hat{u}=\frac{u}{U_0},\hat{t}=\frac{t\mu}{\rho h^2},\hat{p}=\frac{ph}{\mu U_0},\hat{T}=\frac{T-T_2}{T_1-T_2},S=\frac{\rho v_o h}{\mu},$$

$$Gr=\frac{\rho g h^2\alpha(T_1-T_2)}{\mu U_0},H=\frac{\gamma B_0^2h^2}{\mu},a=\frac{\rho h^2}{\mu},Pr=\frac{\mu c_p}{\kappa},R_d=\frac{\kappa\beta_R}{4\sigma T_2^3} \tag{8}$$

On dropping all hats, equations (2) and (7) become

$$\frac{\partial u}{\partial t} - S\frac{\partial u}{\partial y} = GrT - H(u - a^c t^c) + \frac{\partial^2 u}{\partial y^2} \tag{9}$$

$$\frac{\partial T}{\partial t} - S\frac{\partial T}{\partial y} = \left(\frac{3R_d + 4}{3R_d Pr}\right)\frac{\partial^2 T}{\partial y^2} \tag{10}$$

with boundary conditions

$$u(y,0) = 0,\ u(0,t) = a^c t^c,\ u(1,t) = 0 \tag{11}$$

$$T(y,0) = 0,\ T(0,t) = 1,\ T(1,t) = 0 \tag{12}$$

where S, Gr, H, a, Pr, and Rd are the suction parameter, Grashof number, magnetic parameter, accelerating parameter,Prandtl number and radiation parameter respectively.

NUMERICAL SOLUTION BY THE FINITE ELEMENT METHOD

Spatial Semi-Discretization

We discretize the spatial domain $(0,1)$ into elements $\Omega_1^k = (y_a^k, y_b^k)$ for $k = 1,2,..,r$. We take u_k and T_k to be the approximate solution of u and T respectively. The functions u_k and T_k are defined over Ω_1^k using the Lagrange quadratic interpolation functions ψ_1^k, ψ_2^k and ψ_3^k as basis functions. Under the Galerkin finite element method, we choose the weight functions to be the ψ_i^k, for $i = 1, 2, 3$. According to the weighted integral formulation [16], (9) and (10) become:

$$\int_{\Omega_1^k} \left(\frac{\partial u_k}{\partial t} - S\frac{\partial u_k}{\partial y} - GrT_k + H(u_k - a^c t^c) - \frac{\partial^2 u_k}{\partial y^2}\right)\psi_i^k dy = 0 \tag{13}$$

$$\int_{\Omega_1^k} \left(\frac{\partial T_k}{\partial t} - S\frac{\partial T_k}{\partial y} - \left(\frac{3R_d + 4}{3R_d Pr}\right)\frac{\partial^2 T_k}{\partial y^2}\right)\psi_i^k dy = 0 \tag{14}$$

We take approximations of the form

$$u_k(y,t) = \sum_{j=1}^{3} \xi_j^k(t)\psi_j^k(y),\ T_k(y,t) = \sum_{j=1}^{3} \eta_j^k(t)\psi_j^k(y) \tag{15}$$

Integrating by parts, rearranging and substituting (15) into (13) and (14) gives the semi-discrete system

$$\sum_{j=1}^{3} A_{ij}^k \frac{d\xi_j^k}{dt} + \sum_{j=1}^{3} B_{ij}^{k1}\xi_j^k + \sum_{j=1}^{3} B_{ij}^{k2}\eta_j^k = Q_i^k + f_i^k \tag{16}$$

$$\sum_{j=1}^{3} A_{ij}^k \frac{d\eta_j^k}{dt} + \sum_{j=1}^{3} B_{ij}^{k3}\eta_j^k = R_i^k \tag{17}$$

where

$$A_{ij}^k = \int_{y_1^k}^{y_3^k} \psi_i^k \psi_j^k dy,\ B_{ij}^{k1} = \int_{y_1^k}^{y_3^k} \left(H\psi_i^k \psi_j^k - S\psi_i^k \frac{d\psi_j^k}{dy} + \frac{d\psi_i^k}{dy}\frac{d\psi_j^k}{dy} \right) dy$$

$$B_{ij}^{k2} = \int_{y_1^k}^{y_3^k} -Gr\psi_i^k \psi_j^k dy = -GrA_{ij}^k,\ B_{ij}^{k3} = \int_{y_1^k}^{y_3^k} \left(\left(\frac{3R_d+4}{3R_dPr} \right) \frac{d\psi_i^k}{dy}\frac{d\psi_j^k}{dy} - S\psi_i^k \frac{d\psi_j^k}{dy} \right) dy$$

$$f_i^k = \int_{y_1^k}^{y_3^k} Ha^c t^c \psi_i^k dy,\ Q_i^k = \left[\psi_i^k \sum_{j=1}^{3} \xi_j^k \frac{d\psi_j^k}{dy} \right]_{y_1^k}^{y_3^k},\ R_i^k = \left[\psi_i^k \sum_{j=1}^{3} \left(\frac{3R_d+4}{3R_dPr} \right) \eta_j^k \frac{d\psi_j^k}{dy} \right]_{y_1^k}^{y_3^k}$$

Time Discretization

We now discretize the time domain $(0,L)$ into elements $\Omega_2^n = (t_n, t_{n+1})$ for $n = 1,2,..,N-1$, using the Lagrange linear interpolation functions $\phi_1$and ϕ_2 as basis functions for ξ_j^k and η_j^k. Under the Galerkin finite element method, we choose the weight functions to be the ϕ_s, for $s = 1,2$. Hence, the weighted integral form for (16) and (17) is:

$$\int_{\Omega_2^n} \left(\sum_{j=1}^{3} A_{ij}^k \frac{d\xi_j^k}{dt} + \sum_{j=1}^{3} B_{ij}^{k1} \xi_j^k + \sum_{j=1}^{3} B_{ij}^{k2} \eta_j^k - Q_i^k - f_i^k \right) \phi_s dt = 0 \tag{18}$$

$$\int_{\Omega_2^n} \left(\sum_{j=1}^{3} A_{ij}^k \frac{d\eta_j^k}{dt} + \sum_{j=1}^{3} B_{ij}^{k3} \eta_j^k - R_i^k \right) \phi_s dt = 0 \tag{19}$$

We assume the following forms:

$$Q_i^k(t) = \sum_{m=n}^{n+1} Q_{i,m}^k \phi_{m-n+1}(t),\ R_i^k(t) = \sum_{m=n}^{n+1} R_{i,m}^k \phi_{m-n+1}(t) \tag{20}$$

where $\xi_{j,m}^k = \xi_j^k(t_m)$, $\eta_{j,m}^k = \eta_j^k(t_m)$, $f_{i,m}^k = f_i^k(t_m)$, $Q_{i,m}^k = Q_i^k(t_m)$ and $R_{i,m}^k = R_i^k(t_m)$.

$$\xi_j^k(t) = \sum_{m=n}^{n+1} \xi_{j,m}^k \phi_{m-n+1}(t),\ \eta_j^k(t) = \sum_{m=n}^{n+1} \eta_{j,m}^k \phi_{m-n+1}(t),\ f_i^k(t) = \sum_{m=n}^{n+1} f_{i,m}^k \phi_{m-n+1}(t),$$

After rearranging, substituting (20) into (18) and (19) and taking s=2, we get the fully discretized element equationsin matrix form:

$$\begin{bmatrix} 3\mathbf{A}^k + 2\Delta t\mathbf{B}^{k1} & 2\Delta t\mathbf{B}^{k2} \\ \mathbf{0} & 3\mathbf{A}^k + 2\Delta t\mathbf{B}^{k3} \end{bmatrix} \begin{bmatrix} U_{n+1}^k \\ X_{n+1}^k \end{bmatrix}$$

$$= \begin{bmatrix} 3\mathbf{A}^k - \Delta t\mathbf{B}^{k1} & -\Delta t\mathbf{B}^{k2} \\ \mathbf{0} & 3\mathbf{A}^k - \Delta t\mathbf{B}^{k3} \end{bmatrix} \begin{bmatrix} U_n^k \\ X_n^k \end{bmatrix} + \Delta t \begin{bmatrix} F_n^k + Q_n^k + 2(F_{n+1}^k + Q_{n+1}^k) \\ R_n^k + 2R_{n+1}^k \end{bmatrix}$$

where $\mathbf{A}^k = (A_{ij}^k)$ is the local mass matrix, $\mathbf{B}^{k1} = (B_{ij}^{k1})$, $\mathbf{B}^{k2} = (B_{ij}^{k2})$ and $\mathbf{B}^{k3} = (B_{ij}^{k3})$ are the local stiffness matrices, $\mathbf{0}$ is the zero matrix, $U_n^k = (\xi_{j,n}^k)$ is the local vector of velocity coefficients, $X_n^k = (\eta_{j,n}^k)$ is the local vector of temperature coefficients, and $F_n^k + Q_n^k = (f_{i,n}^k + Q_{i,n}^k)$ and $R_n^k = (R_{i,n}^k)$ are the local force vectors.

For computation of the solution, the spatial domain is divided into 40 line elements, while the time domain is divided into 500 line elements. After assembly of the elements and applying the given boundary conditions (11) and (12), a system of 81 equations is obtained at each time level. This system is solved directly to give the numerical solution for the velocity and temperature.

RESULTS AND DISCUSSIONS

The numerical results were analysed by computing the finite element solution for the velocity and temperature. Different values of the suction parameter, radiation parameter, Grash of number, magnetic parameter and Prandtl number were used in the cases of impulsive (c = 0) and uniformly accelerated (c = 1) movement of the plate at y = 0.The following values of the above parameters were considered: suction parameter S = 1, 3, 5; radiation parameter R_d = 0.1, 1, 10; Grash of number Gr = 1, 5, 10; magnetic parameter H = 2, 4, 6 and Prandtl number Pr = 0.71(for air), 3(for the saturated liquid Freon at 273.3K), 7(for water). The accuracy of the numerical results was verified by comparing the previous results of Rajput and Sahu [13] with the current finite element solution when the parameter S is set to zero. In figures 2 and 3, the velocity and temperature profiles were compared with the available exact solution obtained by Rajput and Sahu. It was observed that the present numerical results are in good agreement with the exact solution.

The effects of the suction parameter S on the time development of the velocity and temperature of the fluid at the centre of the channel (y=0.5) are shown in figures 4-6. It was observed that both the velocity and the temperature of the fluid decrease with increasing suction parameter. The suction and injection through the plates transfer the fluid near the stationary plate (which has lower velocity) to the centre of the channel (which has higher velocity). This causes the flow velocity at the centre of the channel to decrease. Since the fluid near the stationary plate has a lower temperature than the fluid at the centre of the channel, the fluid transfer due to suction and injection results in a decrease in fluid temperature at the centre of the channel.

Figures 7-9 display the effects of the radiation parameter R_d on the time development of the velocity and temperature of the fluid at the centre of the channel (y=0.5). It is observed that increasing R_d decreases the velocity and temperature of the fluid. An increase in the radiation emission, which is represented by R_d, reduces the rate of heat transfer through the fluid. This accounts for the decrease in temperature with increasing R_d. The velocity decreases through the reduction in buoyancy forces associated with the decreased temperature.

Figures 10 and 11 show the effect of the Grash of number Gr on the time development of the fluid velocity at the centre of the channel (y=0.5). It is clear from figures10 and 11 that increasing Gr increases the flow velocity. The Grash of number is proportional to the buoyancy for ces associated with free convection within the fluid. Therefore, the increasing buoyancy forces which are associated with the increasing Grash of number induce an increase in the velocity of the fluid.

The effects of the magnetic parameter H on the time development of the fluid velocity at the centre of the channel (y=0.5) are displayed in figures 12 and 13. From these figures, the velocity is shown to increase with increasing H. An increase in the magnetic parameter results in an increase in the strength of the magnetic field and the associated Lorentz force. Since the magnetic field is considered to be fixed relative to the moving plate, the fluid is pulled more strongly by the magnetic field, which accelerates the fluid flow. The effects of the Prandtl number Pr on the time development of the velocity and temperature of the fluid at the centre of the channel (y=0.5) are shown in figures 14-16. It is observed that increasing Pr decreases the velocity and temperature. An increase in the Prandtl number is consistent with a decrease in thermal conductivity, which results in a decrease in temperature. The flow velocity decreases as a result of reduced buoyancy forces. The Prandtl number is also proportional to the viscosity of the fluid, hence the decrease in fluid velocity when the Prandtl number increases is physically intuitive.

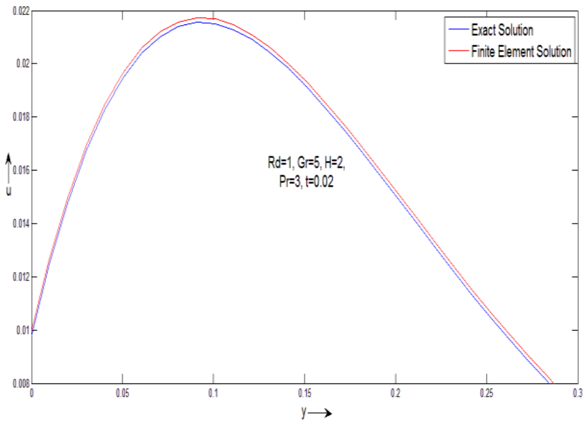

Figure 2: Comparison of Velocity Profiles in the Case of Uniformly Accelerated Movement of the Plate

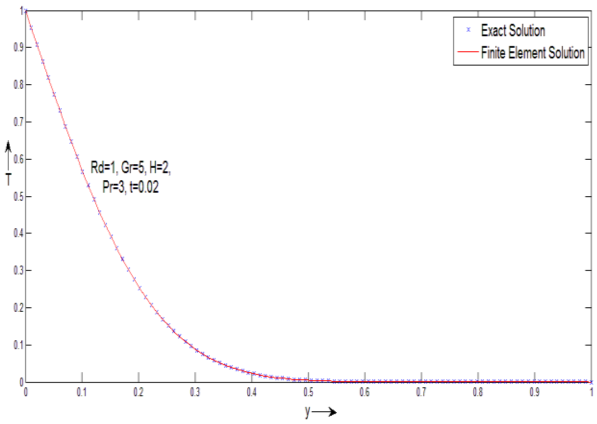

Figure 3: Comparison of Temperature Profiles

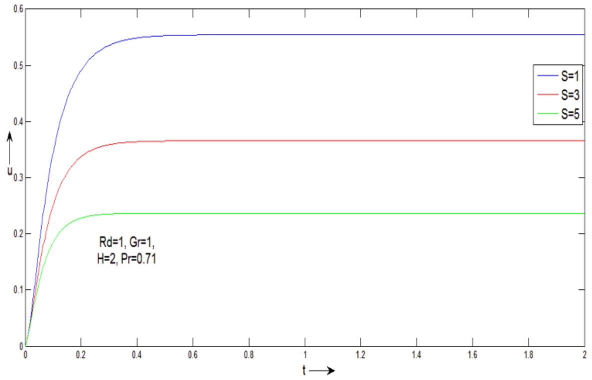

Figure 4: Time Development of Velocity for Different Values of S in the Case of Impulsive Movement of the Plate

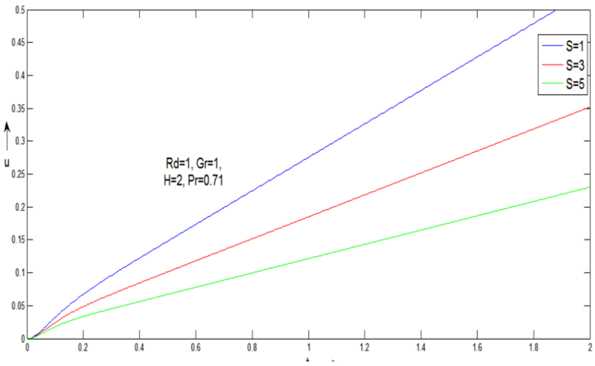

Figure 5: Time Development of Velocity for Different Values of S in the Case of Uniformly Accelerated Movement of the Plate

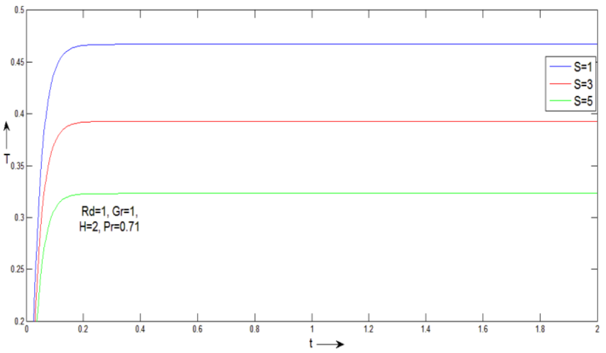

Figure 6: Time Development of Temperature for Different Values of S

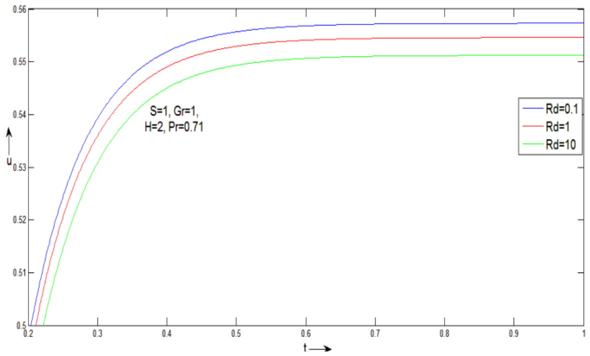

Figure 7: Time Development of Velocity for Different Values of R_d in the Case of Impulsive Movement of the Plate

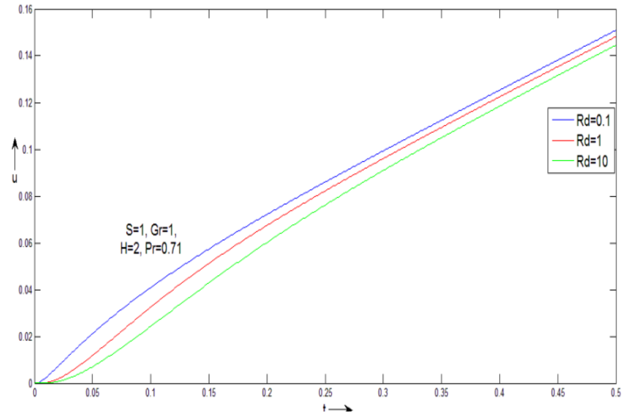

Figure 8: Time Development of Velocity for Different Values of R_d in the Case of Uniformly Accelerated Movement of the Plate

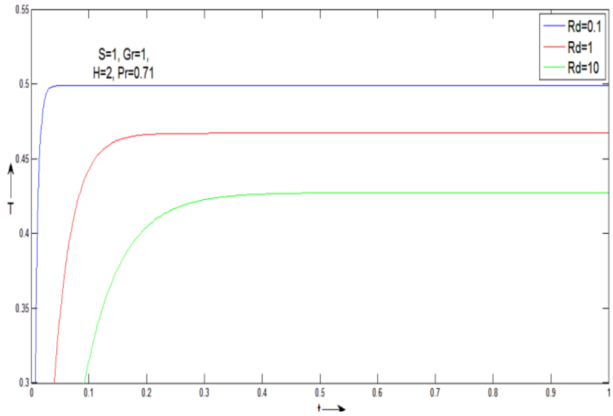

Figure 9: Time Development of Temperature for Different Values of Rd

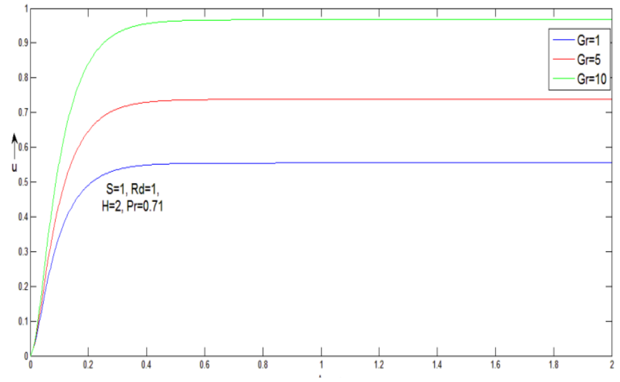

Figure 10: Time Development of Velocity for Different Values of Gr in the Case of Impulsive Movement of the Plate

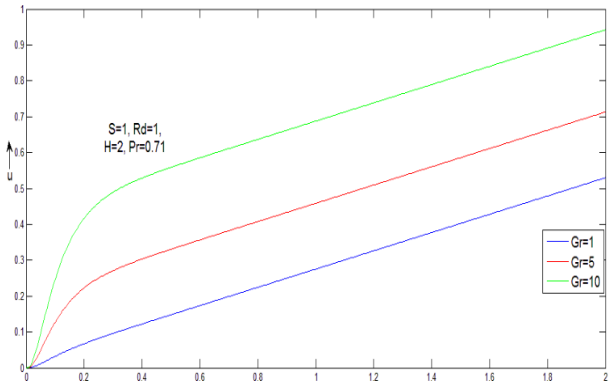

Figure 11: Time Development of Velocity for Different Values of Gr in the Case of Uniformly Accelerated Movement of the Plate

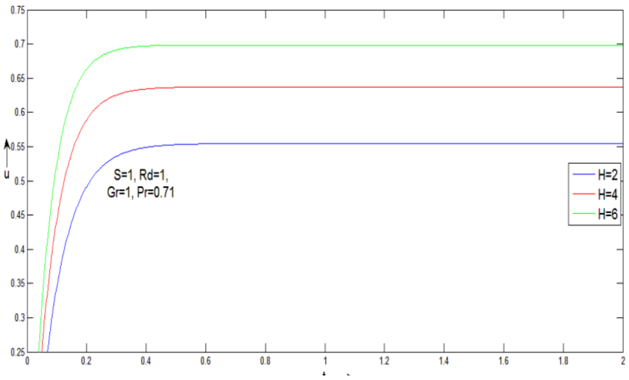

Figure 12: Time Development of Velocity for Different Values of H in the Case of Impulsive Movement of the Plate

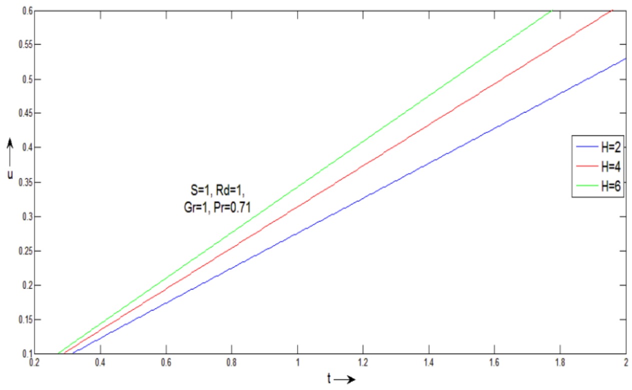

Figure 13: Time Development of Velocity for Different Values of H in the Case of Uniformly Accelerated Movement of the Plate

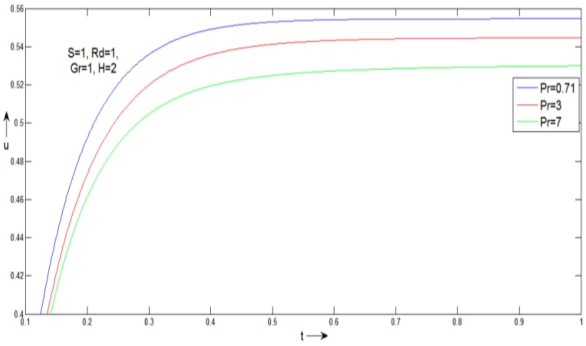

Figure 14: Time Development of Velocity for Different Values of Pr in the Case of Impulsive Movement of the Plate

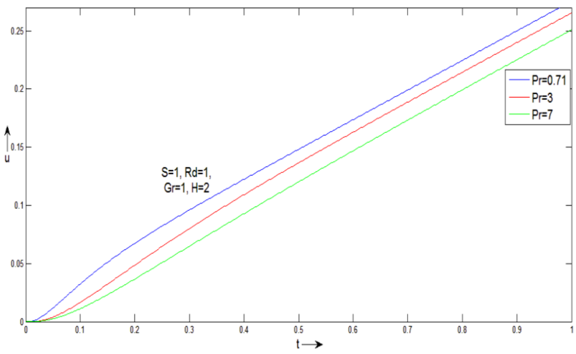

Figure 15: Time Development of Velocity for Different Values of Pr in the Case of Uniformly Accelerated Movement of the Plate

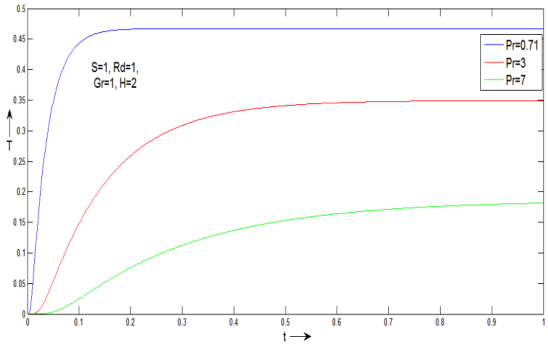

Figure 16: Time Development of Temperature for Different Values of Pr in the Case of Impulsive Movement of the Plate

CONCLUSIONS

In this paper, the unsteady MHD free convection Couette flow of an incompressible viscous fluid between two vertical parallel permeable plates in the presence of thermal radiation was studied. The effects of suction parameter S, radiation parameter Rd, Grash of number Gr, magnetic parameter H and Prandtl number Pr on both the velocity and temperature distributions have been investigated. It was found that the radiation parameter and Prandtl number have a greater effect on the temperature than on the velocity. On the other hand, the magnetic parameter and Grash of number have no effect on the fluid temperature. The findings of this study indicate that the suction parameter, the radiation parameter and the Prandtl number each reduce both the velocity and the temperature of the fluid. The Grash of number and the magnetic parameter increase the fluid velocity.

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