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INFLUENCE OF HALL CURRENT ON AN UNSTEADY FREE CONVECTIVE FLUID FLOW ALONG A FLAT PLATE SURROUNDED BY POROUS MEDIUM IN THE PRESENCE OF MAGNETIC FIELD AND VISCOUS DISSIPATION

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ABSTRACT

The aim of this research work is to study the effect of Hall current on an unsteady magnetohydrodynamic flow of an electrically conducting incompressible fluid flow along an infinite vertical porous flat plate in presence of viscous dissipation and heat absorption. The problem is governed by the non-linear coupled partial differential equations and are solved, numerically by finite element method for velocity, temperature, concentration fields and also the expressions for shearing stress, rate of heat transfer and mass transfer are derived and discussed. The effects of Grashof Number, Modified Grashof Number, Transpiration cooling parameter, Prandtl Number, Schmidt Number, Eckert number, Hartmann number and Hall parameter on the flow field are shown through graphs and tables.

***Keywords**: Hall current; MHD; Free convection; Viscous dissipation; Finite element method;*

NOMENCLATURE

List of Variables:

C'	Concentration of the fluid, *Kg/m*^{3}
C'_w	Concentration near the plate, *Kg/m*^{3}
C'_∞	Concentration in the fluid far away from the plate, *Kg/m*^{3}
T'	Temperature of the fluid , *K*
T'_w	Temperature of the plate, *K*
T'_∞	Temperature of the fluid far away from the plate,
u'	Velocity component in $x'-$direction, *m/s*
w'	Velocity component in $z'-$direction, *m/s*
x'	Spatial co-ordinate along the plate, *m*
y'	Spatial co-ordinate normal to the plate, *m*
k_e	Mean absorption coefficient
$\bar{V}$	Velocity vector, *m/s*
k	Thermal conductivity, *W/mK*
m	Hall parameter
C_p	Specific heat at constant Pressure, *J/kg-K*
D	Chemical molecular diffusivity, *m*^{2}*/s*
U_o	Reference velocity, *m/s*
e	Electron charge, *coulombs*
M	Hartmann number
n_e	Number density of the electron, *kg/m*^{3}
Pr	Prandtl number
P_e	Electron Pressure, *N/ m*^{2}
Sc	Schmidt Number
Gr	Grashof Number
Gc	Modified Grashof Number
g	Acceleration due to Gravity, 9.81 *m/s*^{2}
Ec	Eckert number

Greek Symbols:

ε	Porosity of the porous medium
θ	Dimensionless Temperature (*K*)
ϕ	Dimensionless concentration (*Kg/m*^{3})
ν	Kinematics viscosity, *m*^{2}*/s*
α	Thermal Diffusivity
σ	Electrical conductivity, *mho/m*
μ	Viscosity, *Ns/m*^{2}
μ_e	Magnetic permeability, *Henry/meter*
ρ	Density, *kg/m*^{3}
ω_e	Electron frequency, *radian/sec*
τ_e	Electron collision time, *Sec*
β	Volumetric co-efficient of thermal Expansion, *K*$^-$
β^*	Co-efficient of volume expansion with Species concentration, *m*^{3}*/Kg*

Superscripts:

$'$	Dimensionless Properties

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Subscripts:

p Plate

w Wall condition

∞ Free stream condition

1. INTRODUCTION

In recent years, the analysis of hydromagnetic flow involving heat and mass transfer in porous medium has attracted the attention of many scholars because of its possible applications in diverse fields of science and technology such as-soil sciences, astrophysics, geophysics, nuclear power reactors etc. In geophysics, it finds its applications in the design of MHD generators and accelerators, underground water energy storage system etc. It is worth-mentioning that MHD is now undergoing a stage of great enlargement and differentiation of subject matter. These new problems draw the attention of the researchers due to their varied significance, in liquid metals, electrolytes and ionized gases etc. In addition, the applications of the effect of Hall current on the fluid flow with variable concentration have been seen in MHD power generators, astrophysical and meteorological studies as well as in plasma physics. The Hall Effect is due merely to the sideways magnetic force on the drifting free charges. The electric field has to have a component transverse to the direction of the current density to balance this force. In many works on plasma physics, the Hall Effect is disregarded. But if the strength of magnetic field is high and the number density of electrons is small, the Hall Effect cannot be ignored as it has a significant effect on the flow pattern of an ionized gas. Hall Effect results in a development of an additional potential difference between opposite surfaces of a conductor for which a current is induced perpendicular to both the electric and magnetic field. This current is termed as Hall current. Model studies on the effect of Hall current on MHD convection flows have been carried out by many authors due to application of such studies in the problems of MHD generators and Hall accelerators. Jithender Reddy *et al.* [1] studied finite element analysis of Hall current and Rotation effects on free convection flow past a moving vertical porous plate with Chemical reaction and Heat absorption. Anand Rao and Srinivasa Raju ([2] and [3]) found the numerical solutions of Hall Effect on an unsteady MHD flow and heat transfer along a porous flat plate with Soret, Dufour, mass transfer and viscous dissipation. Anand Rao *et al.* [4] applied Galerkin finite element solution of MHD free convection radiative flow past an infinite vertical porous plate with chemical reaction and hall current. Anand Rao *et al.* [5] found numerical solutions using finite element method of MHD transient flow past an impulsively started infinite horizontal porous plate in a rotating fluid with Hall current. Sarada *et al.* [6] studied unsteady MHD free convection flow near on an infinite vertical plate embedded in a porous medium with Chemical reaction, Hall Current and Thermal radiation. Sudhakar *et al.* [7] studied Hall effect on an unsteady MHD flow past along a porous flat plate with thermal diffusion, diffusion thermo and chemical reaction. Ramana Murthy *et al.* [8] studied heat and mass transfer effects on MHD natural convective flow past an infinite vertical porous plate with thermal radiation and Hall Current. Maddilety and Srinivasa Raju [9] discussed hall effect on an unsteady MHD free convective Couette flow between two permeable plates. Srinivasa Raju and his co-workers ([10]-[13]) studied the effects of transpiration, hall effect, thermal radiation on unsteady MHD free convection fluid flow over an infinite vertical plate in presence of heat and mass transfer. Sivaiah and Srinivasa Raju [14] studied finite element solution of heat and mass transfer flow with hall current, heat source and viscous dissipation. Venkataramana *et al.* [15] studied the combined effects of thermal radiation and rotation effect on an unsteady MHD mixed convection flow through a porous medium with hall current and heat absorption. Dharmendar Reddy and his co-workers ([16] and [17]) studied the effects of chemical reaction and hall current effects on an unsteady MHD free convective flow past a vertical porous plate with heat and mass transfer.

In this paper, the effect of Hall current on an unsteady magnetohydrodynamic flow and mass transfer of an electrically conducting incompressible viscous dissipative fluid along an infinite vertical porous plate is studied. Also, the effects of different flow parameters encountered in the equations are studied. The problem is governed by system of coupled non-linear partial differential equations whose exact solution is difficult to obtain. Hence, the problem is solved by using finite element method, which is more economical from computational view point.

2. MATHEMATICAL FORMULATION

An unsteady free convection flow of an electrically conducting viscous incompressible fluid with mass transfer along a porous flat plate has been considered with viscous dissipation. In Cartesian coordinate system, let $x'-$axis is taken to be along the plate and the $y'-$axis normal to the plate. Since the plate is considered infinite in $x'-$direction, hence all physical quantities will be independent of $x'-$direction. Let the components of velocity along x' and y' axes be u' and v' which are chosen in the upward direction along the plate and normal to the plate respectively. A uniform magnetic field of magnitude B_o is applied normal to the plate. The transverse applied magnetic field and magnetic Reynold's number are assumed to be very small, so that the induced magnetic field is negligible. The polarization effects are assumed to be negligible and hence the electric field is also negligible. Initially, for time $t' \leq 0$, the plate and the fluid are maintained at the same constant temperature $\left(T'_\infty\right)$ in a stationary condition with the same species concentration $\left(C'_\infty\right)$ at all points so that, the Soret and Dufour effects are neglected.

When $t' > 0$, The wall is maintained at constant temperature (T'_w) and concentration (C'_w) higher than the ambient temperature (T'_∞) and concentration (C'_∞) respectively. The homogeneous chemical reaction of first order with rate constant between the diffusing species and the fluid is assumed. Using the relation $\nabla.\overline{H} = 0$ for the magnetic field $\overline{H} = (H_x, H_y, H_z)$, we obtain H_y = constant = H_o (say) where H_o is the externally applied transverse magnetic field so that $\overline{H} = (0, H_o, 0)$.

The equation of conservation of electric charge $\nabla.\overline{J} = 0$ gives j_y = constant, where $\overline{J} = (j_x, j_y, j_z)$. We further assume that the plate is non-conducting. This implies $j_y = 0$ at the plate and hence zero everywhere.

When the strength of magnetic field is very large, the generalized Ohm's law in the absence of electric field takes the following form:

$$\overline{J} + \frac{\omega_e \tau_e}{B_o} \overline{J} \times \overline{H} = \sigma\left(\mu_e \overline{V} \times \overline{H} + \frac{1}{en_e} \nabla P_e \right) \tag{1}$$

Under the assumption that the electron pressure (for weakly ionized gas), the thermo-electric pressure and ion-slip conditions are negligible, equation (1) becomes:

$$j_x = \frac{\sigma \mu_e H_o}{1+m^2}\left(mu' - w'\right) \text{ and } j_z = \frac{\sigma \mu_e H_o}{1+m^2}\left(mw' + u'\right) \tag{2}$$

Where u' is the $x'-$component of $\overline{V}$, w' is the $z'-$component of $\overline{V}$ and $m\ (=\omega_e \tau_e)$ is the hall parameter. Within the above framework, the equations which govern the flow under the usual Boussinesq's approximation are as follows:

$$\frac{\partial v'}{\partial y'} = 0 \tag{3}$$

$$\frac{\partial u'}{\partial t'} + v'\frac{\partial u'}{\partial y'} = \upsilon \frac{\partial^2 u'}{\partial y'^2} - \frac{\sigma \mu^2{}_e H_o^2}{\rho\left(1+m^2\right)}\left(u' + mw'\right) + g\beta\left(T' - T'_\infty\right) + g\beta^*\left(C' - C'_\infty\right) \tag{4}$$

$$\frac{\partial w'}{\partial t'} + v'\frac{\partial w'}{\partial y'} = \upsilon \frac{\partial^2 w'}{\partial y'^2} - \frac{\sigma \mu^2{}_e H_o^2}{\rho\left(1+m^2\right)}\left(w' - mu'\right) \tag{5}$$

$$\frac{\partial T'}{\partial t'} + v'\frac{\partial T'}{\partial y'} = \frac{k}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} + \frac{\nu}{C_p}\left(\frac{\partial u'}{\partial y'}\right)^2 \tag{6}$$

$$\frac{\partial C'}{\partial t'} + v'\frac{\partial C'}{\partial y'} = D\frac{\partial^2 C'}{\partial y'^2} \tag{7}$$

The corresponding initial and boundary conditions are:

$$\left.\begin{array}{l} t' \le 0: \ u' = 0, \quad w' = 0, \ T' = T'_{\infty,} \ C' = C'_\infty \quad for\ all \quad y' \\ t' > 0: \begin{cases} u' = 0, \quad w' = 0, \ T' = T'_{w,} \ C' = C'_w \quad at \quad y' = 0 \\ u' = 0, \quad w' = 0, \ T' = T'_{\infty,} \ C' = C'_\infty \quad as \quad y' \to \infty \end{cases} \end{array}\right\} \tag{8}$$

The non-dimensional quantities introduced in the equations (3)-(7) are:

$$\left.\begin{array}{l} t = \dfrac{t' U_o^2}{\upsilon}, \ \ y = \dfrac{y' U_o^2}{\upsilon}, \ (u, v, w) = \dfrac{(u', v', w')}{U_o}, \ \ \theta = \dfrac{(T' - T'_\infty)}{(T'_w - T'_\infty)}, \ \varphi = \dfrac{(C' - C'_\infty)}{(C'_w - C'_\infty)}, \ M = \dfrac{\sigma \mu_e^2 H_0^2 \upsilon}{\rho U_o^2}, \\ Ec = \dfrac{U_o^2}{C_p (T'_w - T'_\infty)}, \ Sc = \dfrac{\upsilon}{D}, \ \ Gr = \dfrac{\upsilon g \beta (T'_w - T'_\infty)}{U_o^3}, \\ Gc = \dfrac{\upsilon g \beta^* (C'_w - C'_\infty)}{U_o^3}, \ \Pr = \dfrac{\mu C_p}{k}, \end{array}\right\} \tag{9}$$

The governing equations can be obtained in the dimensionless form as:

$$\frac{\partial v}{\partial y}=0 \tag{10}$$

$$\frac{\partial u}{\partial t}+v\frac{\partial u}{\partial y}=\frac{\partial^2 u}{\partial y^2}-\frac{M}{\left(1+m^2\right)}\left(u+mw\right)+(Gr)\theta+(Gc)\phi \tag{11}$$

$$\frac{\partial w}{\partial t}+v\frac{\partial w}{\partial y}=\frac{\partial^2 w}{\partial y^2}-\frac{M}{\left(1+m^2\right)}\left(w-mu\right) \tag{12}$$

$$\frac{\partial \theta}{\partial t}+v\frac{\partial \theta}{\partial y}=\frac{1}{\Pr}\frac{\partial^2 \theta}{\partial y^2}+(Ec)\left(\frac{\partial u}{\partial y}\right)^2$$

(13)

$$\frac{\partial \phi}{\partial t}+v\frac{\partial \phi}{\partial y}=\frac{1}{Sc}\frac{\partial^2 \phi}{\partial y^2} \tag{14}$$

The initial and boundary conditions (8) in the non-dimensional form are:

$$\left.\begin{array}{l} t\le 0: u=0,\ w=0,\ \theta=0,\ \phi=0 \quad for\,all\ \ y \\ t>0:\begin{cases} u=0,\ w=0,\ \theta=1,\ \phi=1 & at\ y=0 \\ u=0,\ w=0,\ \theta=0,\ \phi=0 & as\ y\to\infty \end{cases}\end{array}\right\} \tag{15}$$

The skin-friction, Nusselt number and Sherwood number are important physical parameters for this type of boundary layer flow.

The skin-friction coefficient at the wall along x' - axis is given by

$$\tau_1=\left(\frac{\partial u}{\partial y}\right)_{y=0} \tag{16}$$

The skin-friction coefficient at the wall along z' - axis is given by

$$\tau_2=\left(\frac{\partial w}{\partial y}\right)_{y=0} \tag{17}$$

The rate of heat transfer coefficient (Nusselt number) due to temperature profiles is given by

$$Nu=\left(\frac{\partial \theta}{\partial y}\right)_{y=0} \tag{18}$$

And the rate of mass transfer coefficient (Sherwood number) due to concentration profiles is given by

$$Sh=\left(\frac{\partial \phi}{\partial y}\right)_{y=0} \tag{19}$$

3. NUMERICAL SOLUTIONS BY FINITE ELEMENT TECHNIQUE

Finite Element Technique: The finite element procedure (FEM) is a numerical and computer based method of solving a collection of practical engineering problems that happen in different fields such as, in heat transfer, fluid mechanics ([18]-[55]) and many other fields. It is recognized by developers and consumers as one of the most influential numerical analysis tools ever devised to analyze complex problems of engineering. The superiority of the method, its accuracy, simplicity, and computability all make it a widely used apparatus in the engineering modeling and design process. It has been applied to a number of substantial mathematical models, whose differential equations are solved by converting them into a matrix equation. The primary feature of FEM ([55] and [56]) is its ability to describe the geometry or the media of the problem being analyzed with huge flexibility. This is because the discretization of the region of the problem is performed using highly flexible uniform or non uniform pieces or elements that can easily describe complex shapes. The method essentially consists in assuming the piecewise continuous function for the results and getting the parameters of the functions in a manner that reduces the fault in the solution. The steps occupied in the finite element analysis areas follows.

Step 1: Discretization of the Domain The fundamental concept of the FEM is to divide the region of the problem into small connected pieces, called finite elements. The group of elements is called the finite element mesh. These finite elements are associated in a non overlapping manner, such that they completely cover the entire space of the problem.

Step 2: Invention of the Element Equations

i) A representative element is secluded from the mesh and the variational formulation of the given problem is created over the typical element.

ii) Over an element, an approximate solution of the variational problem is invented, and by surrogating this in the system, the element equations are generated.

iii) The element matrix, which is also known as stiffness matrix, is erected by using the element interpolation functions.

Step 3: Assembly of the Element Equations The algebraic equations so achieved are assembled by imposing the inter element continuity conditions. This yields a large number of mathematical equations known as the global finite element model, which governs the whole domain.

Step 4: Imposition of the Boundary Conditions On the accumulated equations, the Dirichlet's and Neumann boundary conditions (15) are imposed.

Step 5: Solution of Assembled Equations The assembled equations so obtained can be solved by any of the numerical methods, namely, Gauss elimination technique, LU decomposition technique, and the final matrix equation can be solved by iterative technique. For computational purposes, the coordinate y varies from 0 to 9, where y_{max} represents infinity external to the momentum, energy and concentration edge layers.

In one-dimensional space, linear and quadratic elements, or element of higher order can be taken. The entire flow province is divided into 11000 quadratic elements of equal size. Each element is three-noded, and therefore the whole domain contains 21001 nodes. At each node, four functions are to be evaluated; hence, after assembly of the element equations, we acquire a system of 81004 equations which are non-linear. Therefore, an iterative scheme must be developed in the solution. After striking the boundary conditions, a system of equations has been obtained which is solved mathematically by the Gauss elimination method while maintaining a correctness of 0.00001. A convergence criterion based on the relative difference between the present and preceding iterations is employed. When these differences satisfy the desired correctness, the solution is assumed to have been congregated and iterative process is terminated. The Gaussian quadrature is applied for solving the integrations. The computer cryptogram of the algorithm has been performed in MATLAB running on a PC. Excellent convergence was completed for all the results.

4. RESULTS AND DISCUSSIONS

The effect of Hall current on an unsteady magnetohydrodynamic flow and mass transfer of an electrically conducting incompressible viscous dissipative fluid along an infinite vertical porous plate with viscous dissipation has been studied and solved by using finite element method. The effects of material parameters such as Grashof number, Modified Grashof number, Prandtl number, Schmidt number, Hartmann number, Hall parameter and Eckert number separately in order to clearly observe their respective effects on the primary velocity, secondary velocity, temperature and concentration profiles of the flow. Also numerical values of skin-friction coefficients, Nusselt number due to temperature profiles and Sherwood number due to concentration profiles have been discussed in tables-1 and 2 respectively. During the course of numerical calculations of the primary velocity, secondary velocity, temperature and concentration the values of the Prandtl number are chosen for Mercury (Pr = 0.025), Air at $25^{o}C$ and one atmospheric pressure (Pr = 0.71), Water (Pr = 7.00) and Methanol (Pr = 11.62). To focus out attention on numerical values of the results obtained in the study, the values of Sc are chosen for the gases representing diffusing chemical species of most common interest in air namely Hydrogen (Sc=0.22), Helium (Sc = 0.30), Water-vapour (Sc = 0.60), Oxyge (Sc = 0.66) and Ammonia (Sc = 0.78). For the physical significance, the numerical discussions in the problem and at t = 1.0, stable values for primary velocity, secondary velocity, temperature and concentration fields are obtained. To examine the effect of parameters related to the problem on the velocity field and skin-friction numerical computations are carried out at Pr = 0.71. To find out the solution of this problem, we have placed an infinite vertical plate in a finite length in the flow. Hence, we solve the entire problem in a finite boundary. However, in the graphs, the y values vary from 0 to 9, and the primary velocity, secondary velocity, temperature and concentration profiles tend to zero as y tends to 9. This is true for any value of y. Thus, we have considered finite length.

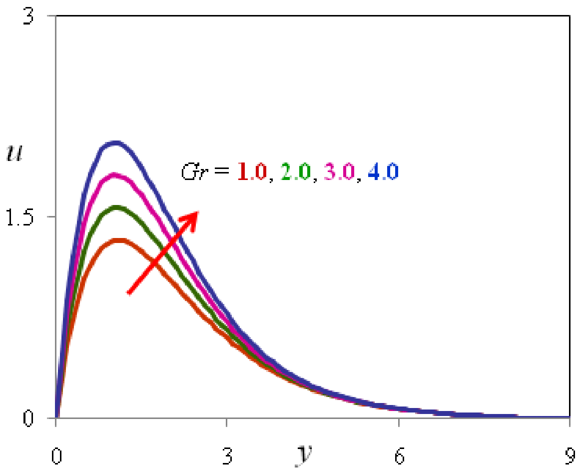

Fig. 1. Influence of *Gr* on primary velocity profiles

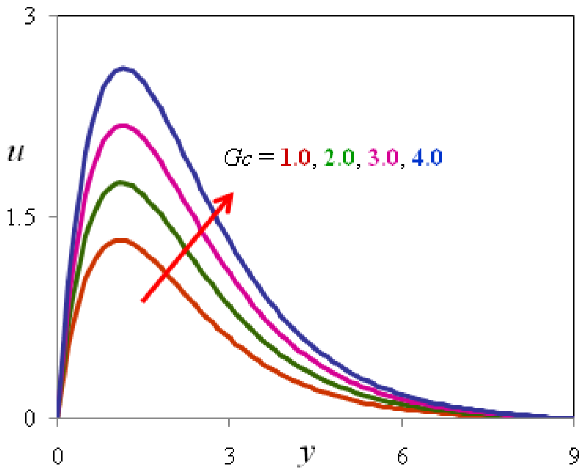

Fig. 2. Influence of *Gc* on primary velocity profiles

The temperature and the species concentration are coupled to the velocity via Grashof number and Modified Grashof number as seen in equation (11). For various values of Grashof number and Modified Grashof number, the primary velocity profiles u are plotted in figures (1) and (2). The Grashof number signifies the relative effect of the thermal buoyancy force to the viscous hydrodynamic force in the boundary layer. As expected, it is observed that there is a rise in the primary velocity due to the enhancement of thermal buoyancy force. Also, as *Gr* increases, the peak values of the primary velocity increases rapidly near the porous plate and then decays smoothly to the free stream velocity. The Modified Grashof number defines the ratio of the species buoyancy force to the viscous hydrodynamic force. As expected, the fluid velocity increases and the peak value is more distinctive due to increase in the species buoyancy force. The primary velocity distribution attains a distinctive maximum value in the vicinity of the plate and then decreases properly to approach the free stream value. It is noticed that the velocity increases with increasing values of Modified Grashof number. The nature of primary velocity profiles in presence of foreign species such as Hydrogen (*Sc* = 0.22), Helium (*Sc* = 0.30), Oxygen (*Sc* = 0.60) and Ammonia (*Sc* = 0.78) are shown in figure (3). The flow field suffers a decrease in primary velocity at all points in presence of heavier diffusing species.

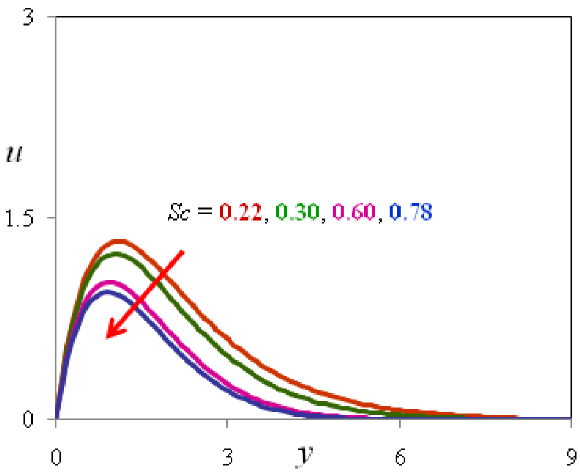

Fig. 3. Influence of *Sc* on primary velocity profiles

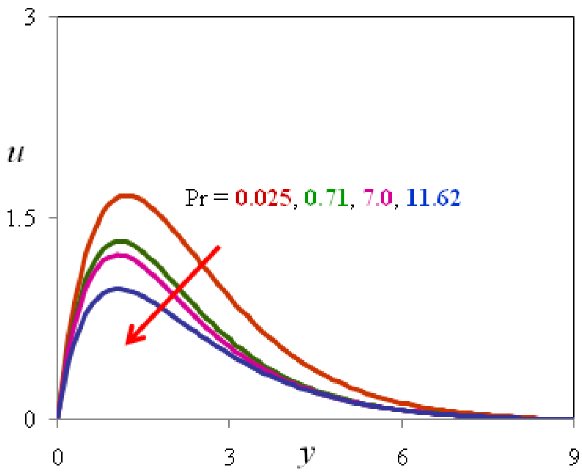

Fig. 4. Influence of Pr on primary velocity profiles

Figure (4) depicts the effect of Prandtl number on primary velocity profiles in presence of foreign species such as Mercury (Pr = 0.025), Air at $25^{o}C$ and one atmospheric pressure (Pr = 0.71), Water (Pr = 7.00) and Methanol (Pr = 11.62) are shown in figure (4). We observe that from figure (4), the primary velocity decreases with increasing of Prandtl number. The effect of the Hartmann number is shown in figure (5). It is observed that, the primary velocity of the fluid decreases with the increasing of the magnetic field number values. The decrease in the primary velocity as the Hartmann number increases is because the presence of a magnetic field in an electrically conducting fluid introduces a force called the Lorentz force, which acts against the flow, if the magnetic field is applied in the normal direction, as in the present study. This resistive force slows down the fluid velocity component as shown in figure (5). Figure (6) depicts the primary velocity profiles as the Hall parameter m increases. We see that u increases as m increases. It can also be observed that u profiles approach their classical values when Hall parameter m becomes large (m > 1).

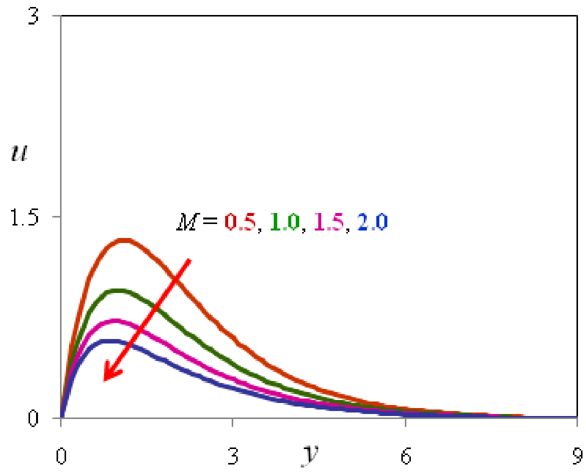

Fig. 5. Influence of *M* on primary velocity profiles

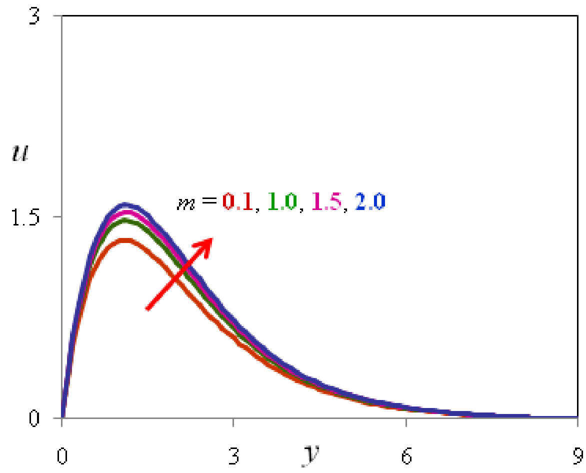

Fig. 6. Influence of *m* on primary velocity profiles

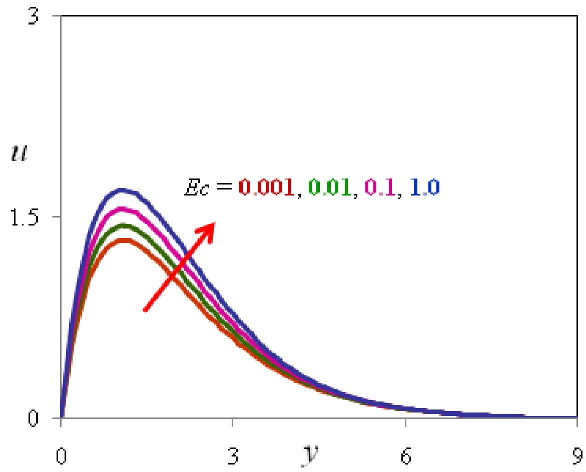

Fig. 7. Influence of *Ec* on primary velocity profiles

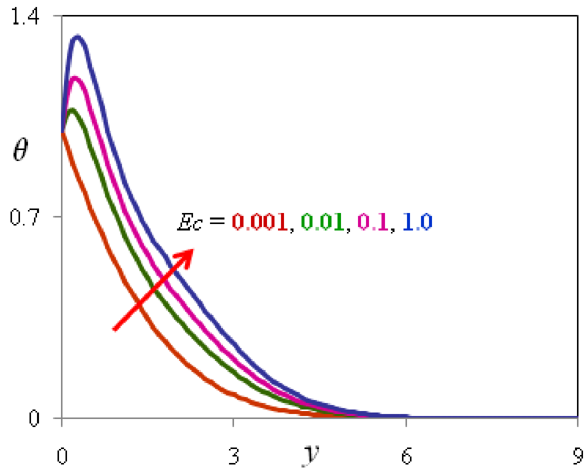

Fig. 8. Influence of *Ec* on Temperature profiles

The influence of the viscous dissipation parameter i.e., the Eckert number on the velocity and temperature are shown in figures (7) and (8) respectively. The Eckert number *expresses* the relationship between the kinetic energy in the flow and the enthalpy. It embodies the conversion of kinetic energy into internal energy by work done against the viscous fluid stresses. Greater viscous dissipative heat causes a rise in the temperature as well as the velocity. This behavior is evident from figures (7) and (8). In figures (9) and (10), we see the influence of the both heat and mass transfer on secondary velocity of the flow. It can be seen that as both the heat and mass transfer increases, this velocity component increases as well. In figures (9) and (10), the effects of the heat and mass transfer on the velocity are displayed. It is apparent from the figures that, the increasing values of heat and mass transfer enhance the secondary velocity. The effect of Eckert number on the secondary velocity flow field is presented in the figure (11). Here, the secondary velocity profiles are drawn against y for three different values of Ec. The Eckert number is found to accelerate the secondary velocity of the flow field at all points. In figure (12) we have the influence of the Hartmann number on the secondary velocity. It can be seen that as the values of this parameter increases, the secondary velocity increases. The nature of secondary velocity profiles in presence of foreign species such as Hydrogen (Sc = 0.22), Helium (Sc = 0.30), Water-vapour (Sc = 0.60) and Ammonia (Sc = 0.78) are shown in figure (13). The flow field suffers a decrease in secondary velocity at all points in presence of heavier diffusing species.

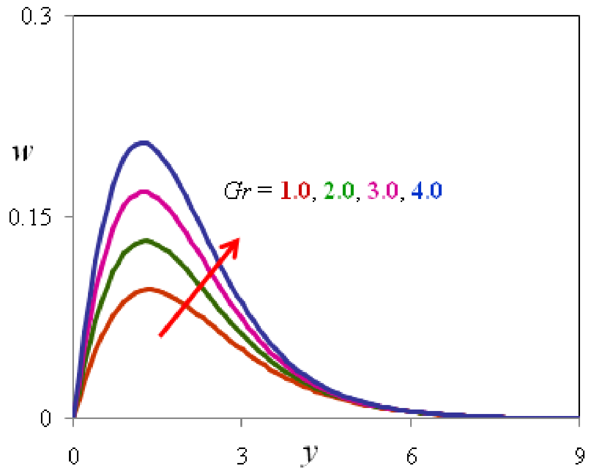

Fig. 9. Influence of *Gr* on secondary velocity profiles

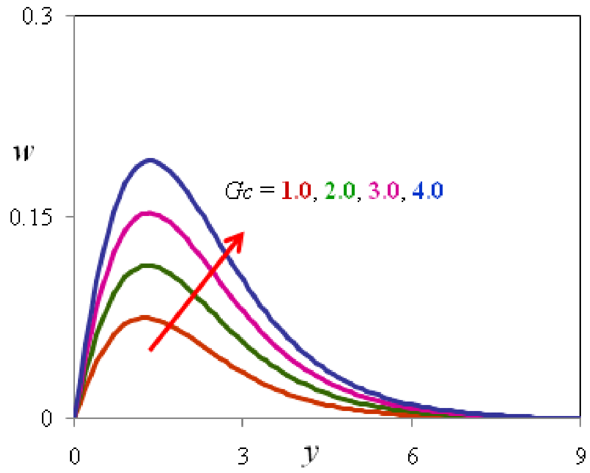

Fig. 10. Influence of *Gc* on secondary velocity profiles

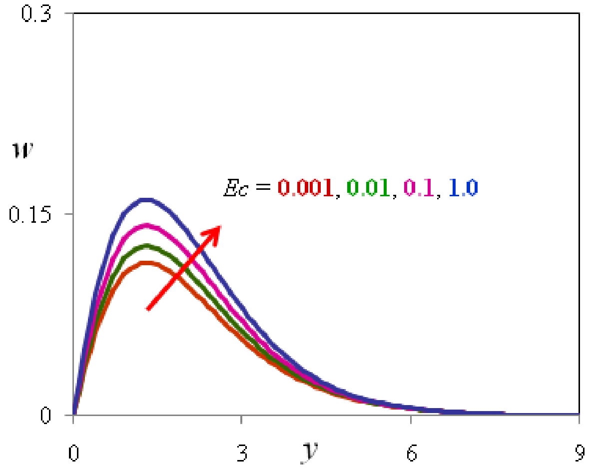

Fig. 11. Influence of *Ec* on secondary velocity profiles

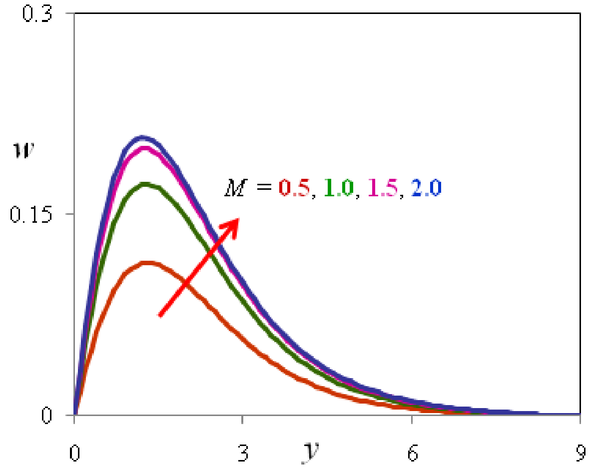

Fig. 12. Influence of *M* on secondary velocity profiles

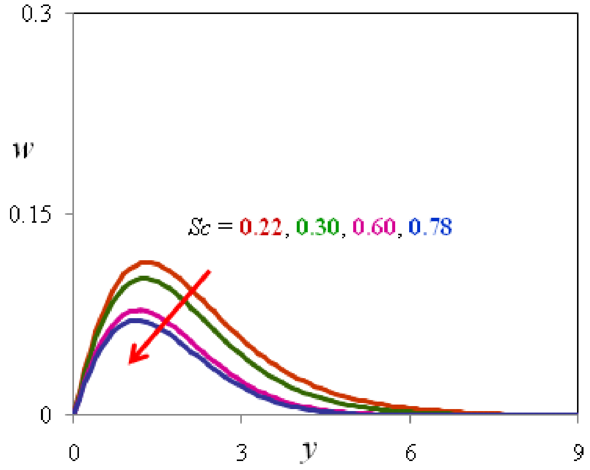

Fig. 13. Influence of *Sc* on secondary velocity profiles

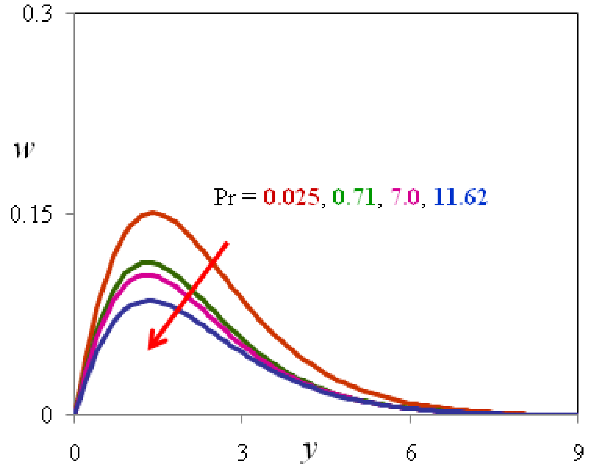

Fig. 14. Influence of Pr on secondary velocity profiles

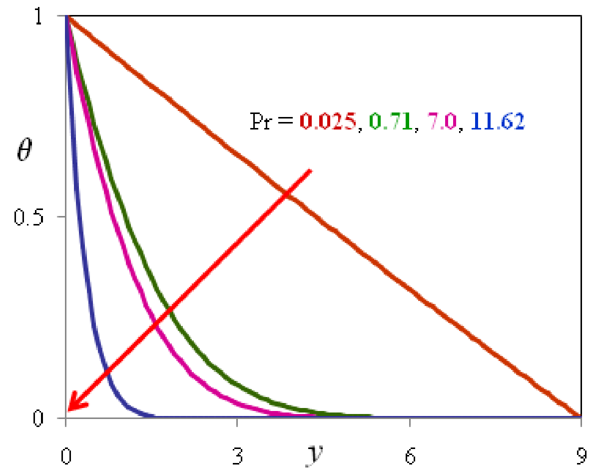

Fig. 15. Influence of Pr on temperature profiles

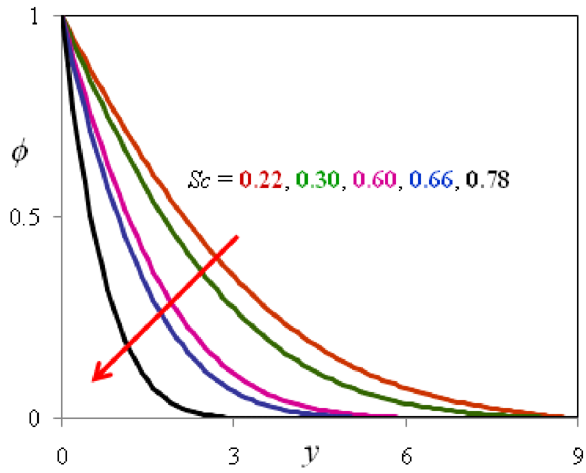

Fig. 16. Influence of *Sc* on concentration profiles

Figure (14) depicts the effect of Prandtl number on secondary velocity profiles in presence of foreign species such as Mercury (Pr = 0.025), Air at 25^oC and one atmospheric pressure (Pr = 0.71), Water (Pr = 7.00) and Methanol (Pr = 11.62) are shown in figure (14). It is observed that, the velocity is decreasing with increasing of Prandtl number. In figure (15) we depict the effect of Prandtl number on the temperature field. It is observed that an increase in the Prandtl number leads to decrease in the temperature field. Also, temperature field falls more rapidly for water in comparison to air and the temperature curve is exactly linear for mercury, which is more sensible towards change in temperature. From this observation it is concluded that mercury is most effective for maintaining temperature differences and can be used efficiently in the laboratory. Air can replace mercury, the effectiveness of maintaining temperature changes are much less than mercury. However, air can be better and cheap replacement for industrial purpose. This is because, either increase of kinematic viscosity or decrease of thermal conductivity leads to increase in the value of Prandtl number. Hence temperature decreases with increasing of Prandtl number. The effects of Schmidt number on the concentration field is presented in figure (16). Figure (16) shows the concentration field due to variation in Schmidt number for the gasses Hydrogen, Helium, Water-vapour, Oxygen and Ammonia. It is observed that, the concentration field is steadily for Hydrogen and falls rapidly for Oxygen and Ammonia in comparison to Water-vapour. Thus Hydrogen can be used for maintaining effective concentration field and Water-vapour can be used for maintaining normal concentration field.

Table-1 shows the variation of shearing stresses $\left(\tau_1 \,\&\, \tau_2\right)$ different values $Gr,\ Gc,\ Sc,\ \Pr,\ M,\ Ec$ and m . From this table-1, it is concluded that the magnitude of shearing stress τ_1 and τ_2 increase as the value of $Gr,\ Gc,\ m,\ Ec$ increase and this behavior is found just reverse with the increase of $\Pr,\ Sc,\ M$. From this table-1, it is also concluded that the magnitude of shearing stress τ_1 and τ_2 increase as the value of $Gr,\ Gc,\ m,\ Ec$ increase and this behavior is found just reverse with the increase of $\Pr,\ Sc,\ M$. Table-2 shows the variation of Nusselt and Sherwood numbers $\left(Nu \,\&\, Sh\right)$ for different values of $Sc,\ \Pr,\ Ec$. From this table-2, it is observed that the Nusselt number increases with increasing the values of Ec and the Nusselt number decreases with increasing values of $\Pr$. From this table-2, it is also observed that, the Sherwood number decreases with increasing values of Sc .

Table-1: Variation of shearing stress τ_1 and τ_2 for different values of $Gr,\ Gc,\ Sc,\ Pr,\ M,\ m,\ Ec,\ Q$ and λ

Gr	Gc	Pr	Sc	M	m	Ec	τ_1	τ_2
1.0	1.0	0.71	0.22	2.0	0.5	0.001	1.1507	0.2336
2.0	1.0	0.71	0.22	2.0	0.5	0.001	1.6979	0.3404
1.0	2.0	0.71	0.22	2.0	0.5	0.001	1.7544	0.3604
1.0	1.0	7.00	0.22	2.0	0.5	0.001	0.7697	0.1404
1.0	1.0	0.71	0.60	2.0	0.5	0.001	1.1070	0.2180
1.0	1.0	0.71	0.22	4.0	0.5	0.001	0.8314	0.1908
1.0	1.0	0.71	0.22	2.0	1.0	0.001	1.2552	0.4211
1.0	1.0	0.71	0.22	2.0	0.5	0.100	1.1537	0.2345

Table-2: Variation of Nusselt and Sherwood numbers $(Nu\,\&\,Sh)$ for different values of $\Pr$, Sc and Ec

$\Pr$	Ec	Nu	Sc	Sh
0.71	0.001	2.0365	0.22	1.5474
7.00	0.001	1.9542	0.30	1.4162
0.71	0.100	2.0985	0.60	1.3852

5. CONCLUSIONS

The problem The effect of Hall current on unsteady MHD flow of an electrically conducting incompressible fluid along a porous flat plate with viscous dissipation is studied. The dimensionless equations are solved by using finite element method. The Effects of primary velocity, secondary velocity, temperature and concentration for different parameters like Gr, Gc, $\Pr$, Sc, M, m and Ec are studied. The study concludes the following results.

1. It is observed that both the primary and secondary velocities of the fluid increases with the increasing of parameters Gr, Gc, m, Ec and decreases with the increasing of parameters $\Pr$, M, Sc.
2. The fluid temperature increases with the increasing of Ec and decreases with the increasing of $\Pr$.
3. The Concentration of the fluid decreases with the increasing of Sc.
4. From table-1, it is concluded that the magnitude of shearing stress τ_1 and τ_2 increases as the increasing values of Gr, Gc, m, Ec and this behavior is found just reverse with the increasing of $\Pr$, Sc and M.
5. From table-2, it is concluded that the Nusselt number (Nu) due to temperature profiles are increasing with increasing values of Ec and this behavior is found just reverse with the increasing of $\Pr$.
6. From table-2, it is concluded that the Sherwood number (Sh) due to concentration profiles are decreasing with increasing values of Sc.

REFERENCES

1. G. Jithender Reddy, R. Srinivasa Raju, J. Anand Rao, Finite element analysis of Hall current and Rotation effects on free convection flow past a moving vertical porous plate with Chemical reaction and Heat absorption, *Proceedings of 59th Congress of ISTAM*, Vol. 59-istam-fm-fp-29, pp.1-11, 2014.
2. J. Anand Rao and R. Srinivasa Raju, Hall Effect on an unsteady MHD flow and heat transfer along a porous flat plate with mass transfer and viscous dissipation, *Journal of Energy, Heat and Mass Transfer*, Vol. 33, pp. 313-332, 2011.
3. J. Anand Rao and R. Srinivasa Raju, The effects of Hall currents, Soret and Dufour on MHD flow and heat transfer along a porous flat plate with mass transfer, *Journal of Energy, Heat and Mass Transfer*, Vol. 33, pp. 351-372, 2011.
4. J. Anand Rao, P. Ramesh Babu, R. Srinivasa Raju, Galerkin finite element solution of MHD free convection radiative flow past an infinite vertical porous plate with chemical reaction and hall current, *International Journal of Mathematical Archive*, Vol. 6, No. 9, pp. 164-177, 2015.
5. J. Anand Rao, R. Srinivasa Raju, S. Sivaiah, Finite Element Solution of MHD transient flow past an impulsively started infinite horizontal porous plate in a rotating fluid with Hall current, *Journal of Applied Fluid Mechanics*, Vol. 5, No. 3, pp. 105-112, 2012.
6. K. Sarada, R. Srinivasa Raju, B. Shankar, Unsteady MHD free convection flow near on an infinite vertical plate embedded in a porous medium with Chemical reaction, Hall Current and Thermal radiation, *International Journal of Scientific and Innovative Mathematical Research*, Vol. 3, Special Issue 3, pp. 795-801, 2015.
7. K. Sudhakar, R. Srinivasa Raju, M. Rangamma, Hall effect on an unsteady MHD flow past along a porous flat plate with thermal diffusion, diffusion thermo and chemical reaction, *Journal of Physical and Mathematical Sciences*, Vol. 4, No. 1, pp. 370-395, 2013.
8. M. V. Ramana Murthy, R. Srinivasa Raju, J. Anand Rao, Heat and Mass transfer effects on MHD natural convective flow past an infinite vertical porous plate with thermal radiation and Hall Current, *Procedia Engineering Journal*, Vol. 127, pp. 1330-1337, 2015.
9. P. Maddilety, R. Srinivasa Raju, Hall effect on an unsteady MHD free convective Couette flow between two permeable plates, *Global Journal of Pure and Applied Mathematics*, Vol. 11, No. 2, pp. 125-129, 2015.
10. R. Srinivasa Raju, G. Anitha and G. Jitthender Reddy, Influence of Transpiration and Hall effects on unsteady MHD free convection fluid flow over an infinite vertical plate, *International Journal of Control Theory and Applications*, 2016 (In Press).
11. R. Srinivasa Raju, M. Anil Kumar, N. Venkatesh, Transpiration Influence On An Unsteady Natural Convective Fluid Flow Past An Infinite Vertical Plate Embedded In Porous Medium In Presence Of Hall Current Via Finite Element Method, *ARPN Journal of Engineering and Applied Sciences*, 2016 (In Press).

12. R. Srinivasa Raju, S. Sivaiah, J. Anand Rao, Finite Element Solution of Heat and Mass transfer in past an impulsively started infinite vertical plate with Hall Effect, *Journal of Energy, Heat and Mass Transfer*, Vol. 34, pp. 121-142, 2012.
13. R. Srinivasa Raju, S. Sivaiah, J. Anand Rao, Radiation effects on unsteady MHD free convection with Hall current near on an infinite vertical porous plate, *Journal of Energy, Heat and Mass Transfer*, Vol. 34, pp. 163-174, 2012.
14. S. Sivaiah, R. Srinivasa Raju, Finite Element Solution of Heat and Mass transfer flow with Hall Current, heat source and viscous dissipation, *Applied Mathematics and Mechanics*, Vol. 34, No. 5, pp. 559-570, 2013.
15. S. Venkataramana, K. Anitha, R. Srinivasa Raju, Thermal radiation and rotation effect on an unsteady MHD mixed convection flow through a porous medium with Hall current and Heat absorption, *International Journal of Mathematical Sciences, Technology and Humanities*, Vol. 2, Issue 4, pp. 593-615, 2012.
16. Y. Dharmendar Reddy, R. Srinivasa Raju, S. Hari Prasad, L. Anand Babu, Chemical Reaction effect on an unsteady MHD free convective flow past a vertical porous plate with Hall Current, *Proceedings of International Conference on Mathematical Computer Engineering (ICMCE-2013)*, pp. 1206-1219 with ISBN 978-93-82338-91-8 © 2013 Bonfring.
17. Y. Dharmendar Reddy, R. Srinivasa Raju, V. Srinivasa Rao, L. Anand Babu, Hall Current effect on an unsteady MHD free convection flow past a vertical porous plate with heat and mass transfer, *International Journal of Scientific and Innovative Mathematical Research*, Vol. 3, Special Issue 3, pp. 884-890, 2015.
18. G. Aruna, S. Vijay Kumar Varma, R. Srinivasa Raju, Combined influence of Soret and Dufour effects on unsteady hydromagnetic mixed convective flow in an accelerated vertical wavy plate through a porous medium, *International Journal of Advances in Applied Mathematics and Mechanics*, Vol. 3, No. 1, pp. 122-134, 2015.
19. G. Jithender Reddy, J. Anand Rao, R. Srinivasa Raju, Chemical reaction and radiation effects on MHD free convection from an impulsively started infinite vertical plate with viscous dissipation, *International Journal of Advances in Applied Mathematics and Mechanics*, Vol. 2, No. 3, pp. 164-176, 2015.
20. G. Jithender Reddy, J. Anand Rao, R. Srinivasa Raju, Finite element Analysis of MHD free convective Couette flow with Thermal Radiation And Viscous Dissipation, *Proceedings of International Conference on Computers Aided Engineering (CAE-2015)*, pp. 250-255, 2015.
21. G. Jithender Reddy, P. Veera Babu, R. Srinivasa Raju, Finite element analysis of Heat and Mass transfer in MHD radiative free convection from an impulsively started infinite vertical plate, *Proceedings of 59th Congress of ISTAM*, Vol. 59-istam-fm-fp-150, pp.1-8, 2014.
22. G. Jithender Reddy, R. Srinivasa Raju, Siva Reddy Sheri, Finite Element Analysis of Soret and Radiation effects on an transient MHD free convection from an impulsively started infinite vertical plate with Heat absorption, *International Journal of Mathematical Archive*, Vol. 5, No. 4, pp. 211-220, 2014.
23. G. Jitthender Reddy, R. Srinivasa Raju, J. Anand Rao, Influence Of Viscous Dissipation On Unsteady MHD Natural Convective Flow Of Casson Fluid Over An Oscillating Vertical Plate Via FEM, *Ain Shams Engineering Journal*, 2016 (In Press).
24. G. Jitthender Reddy, R. Srinivasa Raju, J. Anand Rao, Thermal Diffusion and Diffusion Thermo Effects on Unsteady MHD Fluid Flow Past A Moving Vertical Plate Embedded in Porous Medium in the Presence of Hall Current and Rotating System, *Transactions of A. Razmadze Mathematical Institute Journal*, Vol. 170, pp. 243-265, DOI: http://dx.doi.org/ 10.1016/j.trmi.2016.07.001, 2016.
25. G. Jitthender Reddy, R. Srinivasa Raju, J. Anand Rao, Thermal Diffusion and Diffusion Thermo impact on Chemical reacted MHD Free Convection from an Impulsively Started Infinite Vertical Plate embedded in a Porous Medium using FEM, *Journal of Porous Media*, 2016 (In Press).
26. J. Anand Rao and R. Srinivasa Raju, Applied magnetic field on transient free convective flow of an incompressible viscous dissipative fluid in a vertical channel, *Journal of Energy, Heat and Mass Transfer*, Vol. 32, pp. 265-277, 2010.
27. J. Anand Rao, G. Jithender Reddy, R. Srinivasa Raju, Finite element study of an unsteady MHD free convection Couette flow with Viscous Dissipation, *Global Journal of Pure and Applied Mathematics*, Vol. 11, No. 2, pp. 65-69, 2015.
28. J. Anand Rao, P. Ramesh Babu, R. Srinivasa Raju, Finite element analysis of unsteady MHD free convection flow past an infinite vertical plate with Soret, Dufour, Thermal radiation and Heat source, *ARPN Journal of Engineering and Applied Sciences*, Vol. 10, No. 12, pp. 5338-5351, 2015.
29. J. Anand Rao, P. Ramesh Babu, R. Srinivasa Raju, Siva Reddy Sheri, Heat and Mass transfer effects on an unsteady MHD free convective chemical reacting fluid flow past an infinite vertical accelerated plate with constant heat flux, *Journal of Energy, Heat and Mass Transfer*, Vol. 36, pp. 237-257, 2014.
30. J. Anand Rao, R. Srinivasa Raju, S. Sivaiah, Finite Element Solution of heat and mass transfer in MHD Flow of a viscous fluid past a vertical plate under oscillatory suction velocity, *Journal of Applied Fluid Mechanics*, Vol. 5, No. 3, pp. 1-10, 2012.
31. J. Anand Rao, S. Sivaiah, R. Srinivasa Raju, Chemical Reaction effects on an unsteady MHD free convection fluid flow past a semi-infinite vertical plate embedded in a porous medium with Heat Absorption, *Journal of Applied Fluid Mechanics*, Vol. 5, No. 3, pp. 63-70, 2012.

32. J. Anand Rao, S. Sivaiah, Sk. Nuslin Bibi, R. Srinivasa Raju, Soret and Radiation effects on unsteady MHD free convective fluid flow embedded in a porous medium with Heat Source, *Journal of Energy, Heat and Mass Transfer*, Vol. 35, pp. 23-39, 2013.
33. K. Sudhakar, R. Srinivasa Raju, M. Rangamma, Chemical reaction effect on an unsteady MHD free convection flow past an infinite vertical accelerated plate with constant heat flux, thermal diffusion and diffusion thermo, *International Journal of Modern Engineering Research*, Vol. 2, Issue 5, pp. 3329-3339, 2012.
34. K. Sudhakar, R. Srinivasa Raju, M. Rangamma, Effects of thermal diffusion and diffusion thermo on an unsteady MHD mixed convection flow past an accelerated infinite vertical plate with viscous dissipation, *International Journal of Mathematical Archive*, Vol. 3, No. 8, pp. 2929-2942, 2012.
35. Ramya Dodda, A. J. Chamkha, R. Srinivasa Raju, J. Anand Rao, Effect of velocity and thermal wall slips on MHD boundary layer viscous flow and heat transfer of a nanofluid over a nonlinearly-stretching sheet: A Numerical study, *Propulsion and Power Research Journal*, 2016 (In Press).
36. Ramya Dodda, R. Srinivasa Raju, J. Anand Rao, Influence Of Chemical Reaction On MHD boundary Layer flow Of Nano Fluids Over A Nonlinear Stretching Sheet With Thermal Radiation, *Journal of Nanofluids*, Vol. 5, No. 6, pp. 880-888, 2016.
37. Ramya Dodda, R. Srinivasa Raju, J. Anand Rao, Slip Effect of MHD Boundary Layer Flow of Nanofluid Particles over a Nonlinearly Isothermal Stretching Sheet in Presence of Heat Generation/Absorption, *International Journal of Nanoscience and Nanotechnology*, 2016 (In Press).
38. S. Sivaiah, G. Murali, M. C. K. Reddy, R. Srinivasa Raju, Unsteady MHD Mixed Convection Flow past a Vertical Porous Plate in Presence of Radiation, *International Journal of Basic and Applied Sciences*, Vol. 1, No. 4, pp. 651-666, 2012.
39. Siva Reddy Sheri, R. Srinivasa Raju, S. Anjan Kumar, Transient MHD free convection flow past a porous vertical plate in presence of viscous dissipation, *International Journal of Advances in Applied Mathematics and Mechanics*, Vol. 2, No. 4, pp. 25-34, 2015.
40. V. Srinivasa Rao, L. Anand Babu, R. Srinivasa Raju, Finite Element Analysis of Radiation and mass transfer flow past semi-infinite moving vertical plate with viscous dissipation, *Journal of Applied Fluid Mechanics*, Vol. 6, No. 3, pp. 321-329, 2013.
41. R. Srinivasa Raju, G. Jithender Reddy, J. Anand Rao, M. M. Rashidi, Rama Subba Reddy Gorla, Analytical and Numerical Study of Unsteady MHD Free Convection Flow over an Exponentially Moving Vertical Plate With Heat Absorption, *International Journal of Thermal Sciences*, Vol. 107, pp. 303-315, 2016.
42. R. Srinivasa Raju, B. Mahesh Reddy, M. M. Rashidi, Rama Subba Reddy Gorla, Application of Finite Element Method to Unsteady MHD Free Convection Flow Past a Vertically Inclined Porous Plate Including Thermal Diffusion And Diffusion Thermo Effects, *Journal of Porous Media*, Vol. 19, Issue. 8, pp. 701-722, 2016.
43. R. Srinivasa Raju, Combined influence of thermal diffusion and diffusion thermo on unsteady hydromagnetic free convective fluid flow past an infinite vertical porous plate in presence of chemical reaction, *Journal of Institution of Engineers: Series C*, pp. 1-11, 2016, DOI: 10.1007/s40032 –016-0258-5.
44. R. Srinivasa Raju, G. Jitthender Reddy, J. Anand Rao, M. M. Rashidi, Thermal Diffusion and Diffusion Thermo Effects on an Unsteady Heat and Mass Transfer MHD Natural Convection Couette Flow Using FEM, *Journal of Computational Design and Engineering*, Vol. 3, Issue 4, pp. 349-362, DOI: 10.1016/j.jcde.2016.06.003, 2016.
45. R. Srinivasa Raju, G. Aruna, N. V. Swamy Naidu, S. Vijay Kumar Varma, M. M. Rashidi, Chemically reacting fluid flow induced by an exponentially accelerated infinite vertical plate in a magnetic field and variable temperature via LTT and FEM, *Theoretical Applied Mechanics*, Vol. 43, Issue 1, pp. 49-83, 2016.
46. R. Srinivasa Raju, Transfer Effects On An Unsteady MHD Free Convective Flow Past A Vertical Plate With Chemical Reaction, *Engineering Transactions Journal*, 2016 (In Press).
47. R. Srinivasa Raju, M. Anil Kumar, Y. Dharmendar Reddy, Unsteady MHD Free Convective Flow Past A Vertical Porous Plate With Variable Suction, *ARPN Journal of Engineering and Applied Sciences*, 2016 (In Press).
48. R. Srinivasa Raju, Application of Finite Element Method to MHD mixed convection chemically reacting flow past a vertical porous plate with Cross Diffusion and Biot number Effects, *American Journal Of Heat And Mass Transfer*, 2016 (In Press).
49. R. Srinivasa Raju, M. Anil Kumar, K. Sarada, Y. Dharmendar Reddy, Influence of thermal radiation on unsteady free convection flow of water near $4^{o}C$ past a moving vertical plate, *Global Journal of Pure and Applied Mathematics*, Vol. 11, No. 2, pp. 237-240, 2015.
50. R. Srinivasa Raju, G. Anitha, G. Aruna, S. Vijay Kumar Varma, Viscous dissipation impact on chemically reacting flow past an infinite vertical oscillating porous plate with magnetic field, *Global Journal of Pure and Applied Mathematics*, Vol. 11, No. 2, pp. 146-150, 2015.
51. R. Srinivasa Raju, G. Jithender Reddy, J. Anand Rao, P. Manideep, Application of FEM to free convective flow of Water near $4^{\circ} C$ past a vertical moving plate embedded in porous medium in presence of magnetic field, *Global Journal of Pure and Applied Mathematics*, Vol. 11, No. 2, pp. 130-134, 2015.

52. R. Srinivasa Raju, K. Sudhakar, M. Rangamma, The effects of thermal radiation and Heat source on an unsteady MHD free convection flow past an infinite vertical plate with thermal diffusion and diffusion thermo, *Journal of Institution of Engineers: Series C*, Vol. 94, Issue 2, pp. 175-186, DOI: 10.1007/s40032-013-0063-3, 2013.
53. R. Srinivasa Raju, G. Jithender Reddy, M. Anil Kumar, N. V. Swamy Naidu, Finite element analysis of chemically reacted fluid flow over an exponentially accelerated vertical plate, *Proceedings of International Conference on Computers Aided Engineering (CAE-2015)*, pp. 243-249, 2015.
54. R. Srinivasa Raju, G. Jithender Reddy, Y. Dharmendar Reddy, J. Anand Rao, Hydromagnetic free convection heat transfer Couette flow of water at $4^{o}C$ in rotating system, *Proceedings of International Conference on Mathematical Computer Engineering (ICMCE-2015)*, 2015.
55. K. J. Bathe, *Finite Element Procedures* (Prentice-Hall, New Jersy), 1996.
56. J. N. Reddy, *An Introduction to the Finite Element Method* (McGraw-Hill, New York), 1985.

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