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The flow with unstable electroconductivity of an MHD fluid over a suddenly accelerated plate – A study

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***Abstract*— The effects of viscosity and thermophoresis on a suddenly accelerated plate with approximated variable electronegativity on an MHD fluid influenced by chemical reaction and radiation are made in this paper and the governing hydrodynamical equations of the physical problem was formulated ; its solutions were analyzed for diverse parameters, such as, Hartmann number (M), electroconductivity (σ), temperature dependent parameter (Pr), Reynold's number (Re), thermal buoyancy (Gr), thermophoresis (Sr) etc. The results were shown through graphs and tables. It is seen that the velocity increases with the magnetic field (M) ; the thermal buoyancy and Solutal buoyancy also increases the velocity ; as a result of sudden movement of the plate, the decrease in electronegativity results in the increase of velocity ; the thermal distribution increases with the increase of Pr, Re, and viscosity ; with the increase of radiation and large amounts of heat absorption, the temperature increases ; with the increase of Sr and Sc, and with the rise in the chemical reaction the concentration distribution of the fluid decreases ; with increase of viscosity a sharp decrease is observed ; with increase of radiation the concentration of the fluid is increased but it decreases in the boundary layer sharply.**

***Index Terms*— Electronegativity, Electroconductivity, Thermal Buoyancy, Reynold's Number, Thermophoresis.**

I. INTRODUCTION

Using Magnetohydrodynamics the interaction of electrically conducting fluids and electromagnetic fields is studied. In variety of engineering processes, agriculture, plasma studies and petroleum industries, Magnetohydrodynamics, thermal radiation and chemical reaction appear. It cannot be overemphasized the interplay of these parameters under consideration in the analysis of suddenly accelerated plate. Several authors contributed to the study of MHD and its ancillary parameters. H Pattayanak and R Mohapatra [2] analyzed in the present study with the influence of thermal radiation, heat generation and chemical reaction on an MHD boundary layer flow past a wedge. This model used for the momentum, temperature and concentration fields. The transmuted model is shown to be controlled by a number of thermo-physical parameters, viz. the magnetic parameter, thermal buoyancy parameter, radiation conduction parameter, heat generation parameter, Porosity parameter, Soret parameter, chemical reaction effect and pressure gradient parameter. They obtained numerical solutions using shooting technique used by Nactsheim-Swigert together with Runge–Kutta six order iteration schemes. M. A. Orukariet al. [3] studied on the influence of viscous dissipation and radiation on magnetohydrodynamic Couette flow in a porous medium was carried out. On the basis of certain simplifying assumptions, the fluid equation of continuity, Navier-Stokes and energy were reduced to mathematical terms, and closed-form analytical solutions of the velocity distribution and energy were obtained on the basis of approximations under the considered parameters. The overall analysis of the study of these parameters in various degrees show an increase in the velocity profile of the fluid, while radiation parameter decreases the temperature distribution; the temperature of the fluid raised by viscous dissipation and Reynolds number increase.

A.T Ngiangia [4] studied on the effects of permeability and radiation on Couette-Poiseuille flow stability. Using the method of undetermined coefficients the solutions to the governing hydrodynamic equations was developed. It was observed that both parameters, affect the stability of Couette-Poiseuille flow on the basis of linear theory using analysis of normal modes, independently but that of radiation is prominent at high wave numbers and Reynolds number regime. Z Boricicet. al. [5] dealt with laminar, unsteady flow with variable fluid electro conductivity of a viscous, incompressible and electro conductive fluid caused by variable motion of flat plate. Velocity of the plate is a function of time and the plate moves in its own plane and in "still" fluid. Present external magnetic field is perpendicular to the plate. The plate temperature is considered to be a function of longitudinal coordinate and time. The viscous and magnetic dissipations, Hole and polarization effects are neglected. General similarity method as well as impulse and energy equation of described problem.[3] and [4] are used to obtain universal equations system. They considered the influence of radiation on MHD Couette and Poiseuille flow in a porous medium and the results in part were in agreement with the results of [5].

A similar study was also carried out by A.T Ngiangia etal. [6] where the effect of radiation and chemical reaction on the reduction of the Ozone layer was investigated. Earlier, P Mebine[7] researched the effect of radiation and other parameters on MHD flow of fluid and made useful findings. C Israel-Cookey et al. [8] researched an unsteady magnetohydrodynamic free convective flow past an infinite vertical heated plate with suction which is time-dependent in an optically thin environment under the influence of viscous dissipation and radiation. The coupled non-linear problem is solved by taking the radiative heat flux in the differential form, and imposing an oscillatory time-dependent perturbation. G. Bodosa and A. K. Borkakat [9] taken two cases of an unsteady two-dimensional flow in the presence of

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a uniform transverse magnetic field of a viscous incompressible and electrically conducting fluid between two parallel plates. Different temperatures are imposed on the plates in case-I and in case-II the upper plate is considered to be moving with constant velocity whereas the lower plate is adiabatic. Fluid velocities and temperatures are obtained and plotted graphically. A. T. Ngiangia and M. A. Orukari [10], also tackled the problem of MHD Couette-Poiseuille flow in a porous medium and stated in part that with the Reynold's number increase temperature increases and with the decrease of velocity they observed the increase of magnetic field. Alalibo T. Ngiangia [11] carried out research on a suddenly accelerated plate with variable approximated electronegativity with MHD fluid provoked by chemical reaction and radiation.

In the present paper the effects of viscosity and thermophoresis on a suddenly accelerated plate with approximated variable electronegativity on an MHD fluid influenced by chemical reaction and radiation are made and the governing hydrodynamical equations of the physical problem was formulated ; its solutions were analyzed for diverse parameters, such as, Hartmann number (M), electroconductivity (σ), temperature dependent parameter (Pr), Reynold's number (Re), thermal buoyancy (Gr), thermophoresis (Sr) etc. The shear stress at the wall of the plate, the rates of heat and mass transfer are also determined. The results were shown through graphs and tables.

II. MATHEMATICAL FORMULATION

- Considered a flat plate as shown in figure 1, extending to large distances in the x and y.
- Considered an incompressible viscous fluid over the half plane y = 0.
- The fluid in contact with the plate be infinite in extent and let it be at rest at time t< 0.
- At t = 0, the plate is suddenly set in motion at a constant velocity U in the x-direction. This generates a two dimensional parallel flow nearby the plate as a result of the parameters affecting the motion of the fluid.

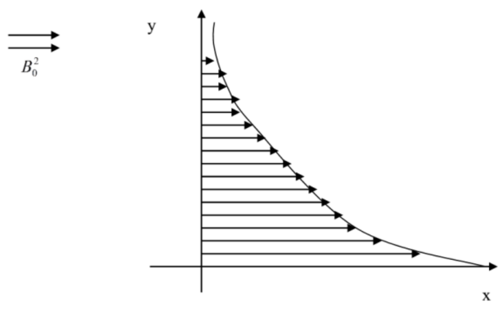

Figure 1. The physical model and coordinate system of the problem.

Since the plate is situated in an infinite fluid, the pressure must be constant everywhere and the governing equations in the non-dimensional form along with the boundary and initial conditions is therefore

$$\frac{\partial u}{\partial t} = \frac{1}{\mathrm{Re}}\frac{\partial^2 u}{\partial y^2} - \left(M + \sigma_0 + \frac{1}{K}\right)u + Gr\,\theta + Gc\,\phi \quad (2.1)$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{\mathrm{Pr}}\frac{\partial^2 \theta}{\partial y^2} - (R - Q)\,\theta + Ec\left(\frac{\partial u}{\partial y}\right)^2 \quad (2.2)$$

$$\frac{\partial \phi}{\partial t} = \frac{1}{Sc}\frac{\partial^2 \phi}{\partial y^2} - K_r\,\phi + Sr\frac{\partial^2 \theta}{\partial y^2} \quad (2.3)$$

$$\begin{array}{lll} t < 0 & u = 0,\ \theta = 0,\ \phi = 0 & \text{for all } y \\ t \geq 0 & \begin{cases} u = R,\ \theta = 1,\ \phi = 1 & y = 0 \\ u = 0,\ \theta = 0,\ \phi = 0 & y \to \infty \end{cases} \end{array} \quad (2.4)$$

III. FINITE DIFFERENCE SCHEME

Since the governing equations are non-linear in nature, these are solved using explicit finite difference scheme. The governing equations along with the boundary conditions in the finite difference form are

$$\frac{u(i,j+1) - u(i,j)}{\Delta t} = \frac{1}{\mathrm{Re}}\frac{u(i+1,j) - 2u(i,j) + u(i-1,j)}{\Delta y^2} - \left(M + \sigma_0 + \frac{1}{K}\right)u(i,j) + Gr\,\theta(i,j) + Gc\,\phi(i,j) \quad (3.1)$$

$$\frac{\theta(i,j+1) - \theta(i,j)}{\Delta t} = \frac{1}{\mathrm{Pr}}\frac{\theta(i+1,j) - 2\theta(i,j) + \theta(i-1,j)}{\Delta y^2} - (R - Q)\,\theta(i,j) - Ec\left[\frac{u(i+1,j) - u(i,j)}{\Delta y}\right]^2$$

$$\frac{\phi(i,j+1) - \phi(i,j)}{\Delta t} = \frac{1}{\mathrm{Sc}}\frac{\phi(i+1,j) - 2\phi(i,j) + \phi(i-1,j)}{\Delta y^2} - Kr\,\phi(i,j) + Sr\frac{\theta(i+1,j) - 2\theta(i,j) + \theta(i-1,j)}{\Delta y^2} \quad (3.2)$$

$$u(i,0) = 0,\quad \theta(i,0) = 0,\quad \phi(i,0) = 0 \quad \text{for all } i \quad (3.3)$$

$$u(0,j) = R,\quad \theta(0,j) = 1,\quad \phi(0,j) = 1 \quad \text{for all } j \quad (3.4)$$

$$u(i,j) \to 0,\quad \theta(i,j) \to 0,\quad \phi(i,j) \to 0 \quad \text{for all } j$$

The suffixes, *i* corresponds to *y* and *j* corresponds to *t* and $\Delta t = t(j+1) - t(j)$ and $\Delta y = y(i+1) - y(i)$. The computations were carried out for different values the various physical parameters.

IV. STABILITY ANALYSIS

- The computations are carried out for different values of the various physical parameters. The procedure is repeated until the steady state. During computation Δt was chosen as 0.001.

- To judge the accuracy of the convergence of the finite difference scheme, the same program was run with Δt= 0.0009and 0.00125 and no significant change was observed. Hence, we conclude the finite difference scheme is stable and convergent.

V. DERIVATIONS

From the velocity, temperature, and concentration fields, the expressions for skin friction coefficient, the rate of heat transfer coefficient in terms of Nusselt number, and the rate of mass transfer in terms of Sherwood number are derived as

$$\tau = \frac{\tau'}{\rho u_0^2} = -\left(\frac{\partial u}{\partial y}\right)_{y=0} \qquad (5.1)$$

$$Nu = -\frac{1}{\theta(0,t)}\left(\frac{\partial \theta}{\partial y}\right)_{y=0} \qquad (5.2)$$

$$Sh = -\left(\frac{\partial \phi}{\partial y}\right)_{y=0} \qquad (5.3)$$

VI. DISCUSSION OF RESULTS

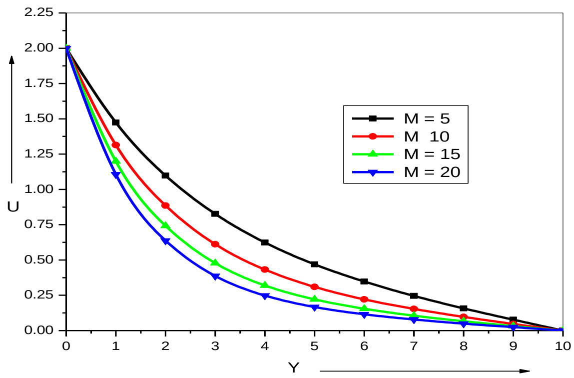

Fig.1 Velocity profiles for different M

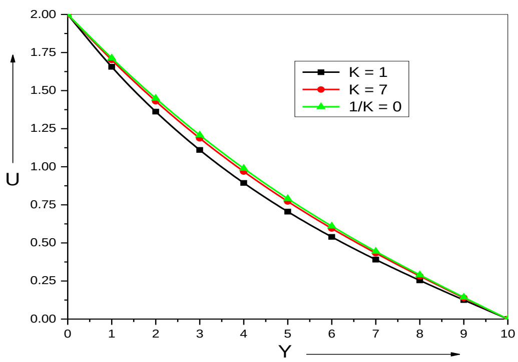

Fig.2 Variation in Velocity profiles for different K

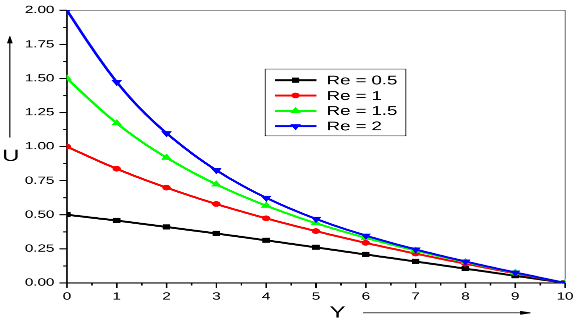

Fig.3 Variation in velocity profiles for different Re

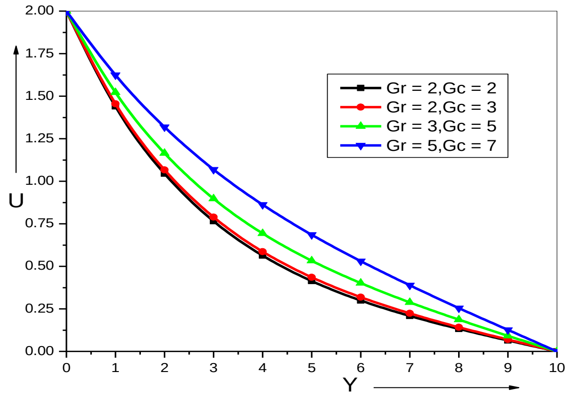

Fig.4 Variation in Velocity Profiles for different Gr & Gc

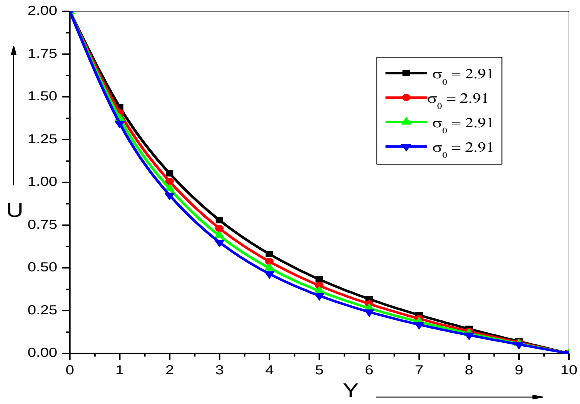

Fig. 5 Variation in Velocity Profiles for different σ_0

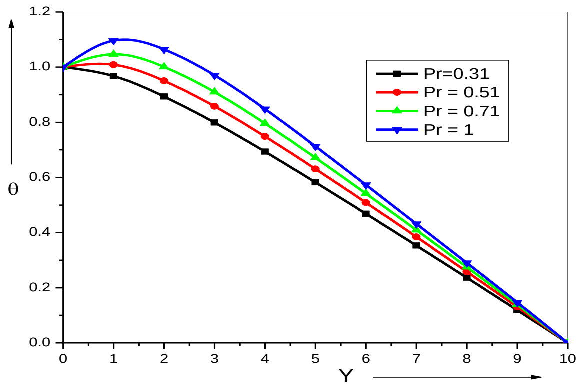

Fig.6 Variation in Temperature profiles for different Pr

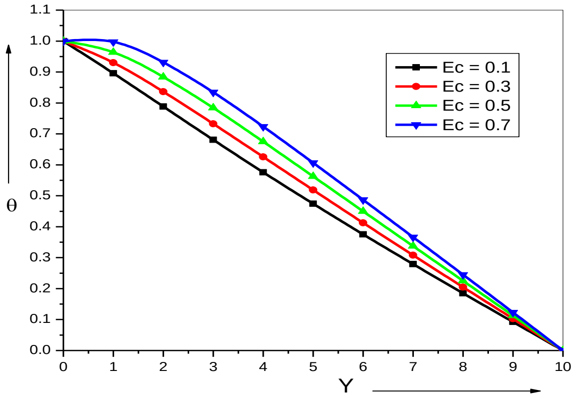

Fig.7 Variation in temperature profiles for different Ec

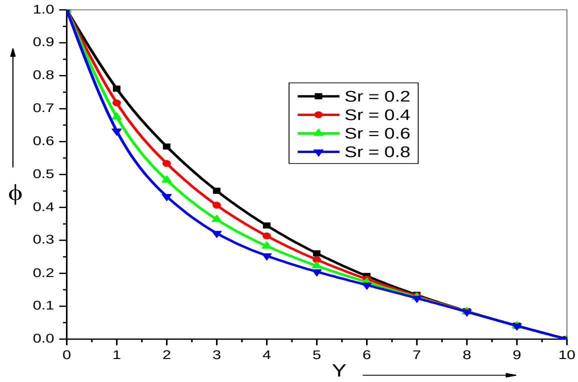

Fig.11. Variation in concentration profiles for different Sr

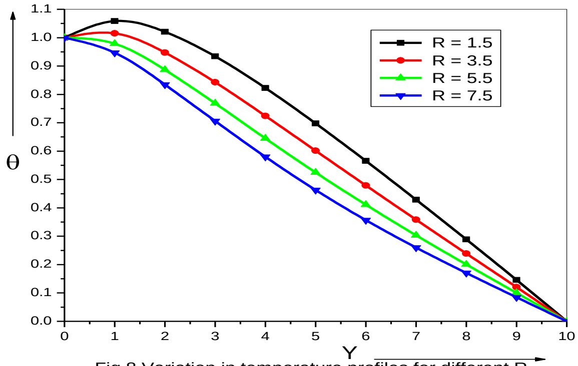

Fig.8 Variation in temperature profiles for different R

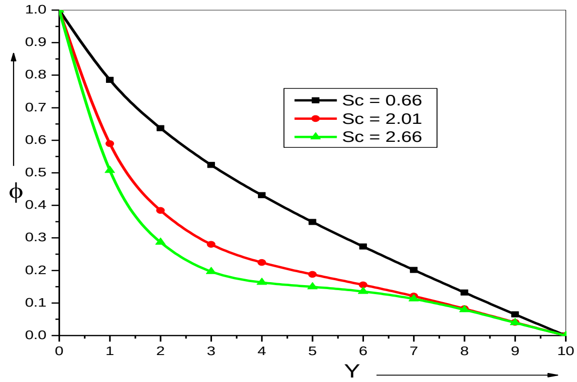

Fig.12 Variation in concentration profiles for different Sc

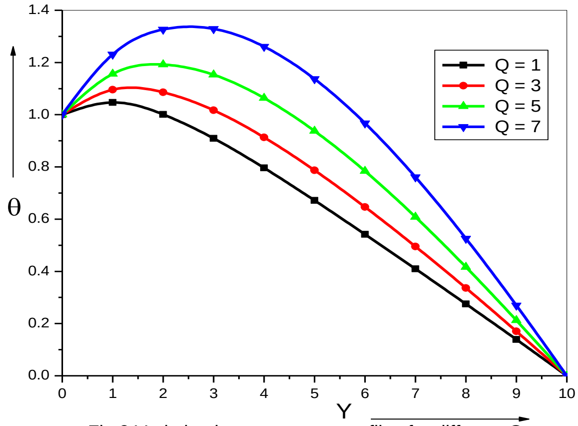

Fig.9 Variation in temperature profiles for different Q

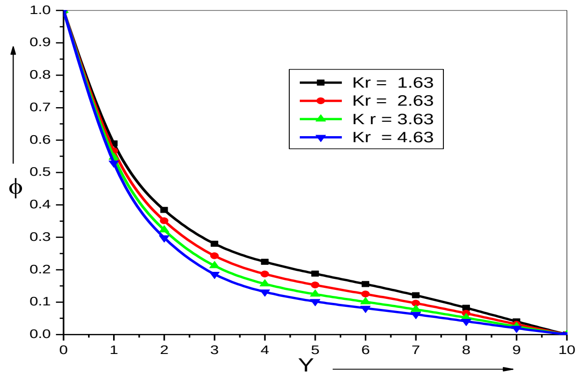

Fig.13 Variation concentration profiles for different Kr

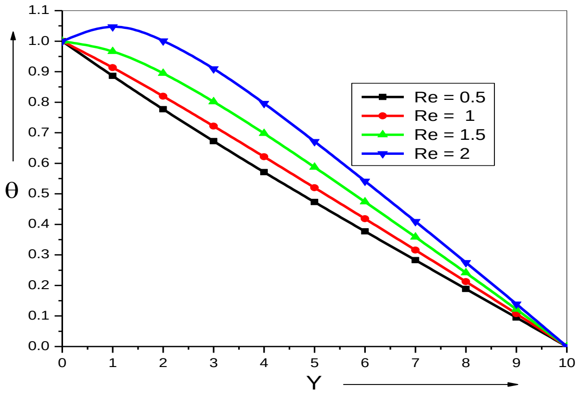

Fig.10 Variation in temperature profiles for different Re

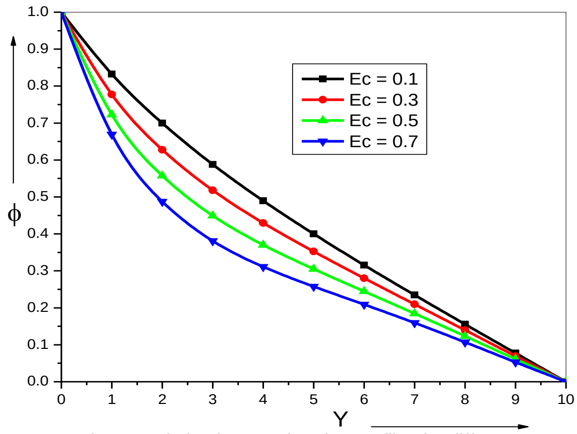

Fig.14 Variation in concebtration profiles for different Ec

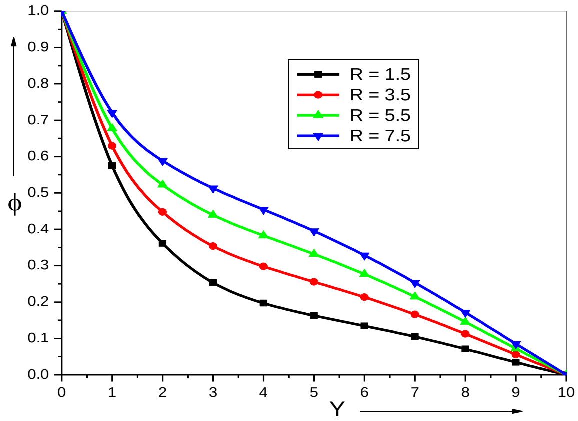

Fig.15 Variation in concentration profiles for different R

The graphs for the velocity profiles are shown from 1 to 5. From the fig.1, it is evident that as the magnetic field (M) increases the velocity decreases which can also be seen from the case of A. T. Ngianga [11]. The variation of velocity with the porosity parameter (K) and the low inertial force (Re) is showed in figures 2 and 3. Raise in the velocity is observed with the increase of the porosity parameter and the low inertial force(Re). This effect is observed by A. T. Ngianga [11] also. The velocity of the fluid increases with the thermal buoyancy (Gr) and Solutal Grashoff number (Gc) which is shown in the comparative figure 4. Figure 5 shows the increase of velocity profile of the fluid with the decrease in electronegativity and is consistent with the studies of A. T. Ngianga [11].

In the figures through 6 to 10, the variation of temperature with various physical parameters is shown and the analysis of temperature distribution is carried out.In figure 6 the variation of Prandtl number for the temperature distribution is given. For small values of Prandtl number, the thermal diffusivity dominates i.e. the temperature increases with the increase of Prandtl number. The increase of temperature distribution is shown for the variation in Eckert number in figure 7. In figures 8 and 9 variations of radiation and heat absorption are shown. The temperature decreases with the increase of Radiation, but with large amounts of heat absorption it increases. It is shown in the figure 10 that temperature increases with the Reynold's number.

From the figures through 11 to 16, the variation of concentration of the fluid is shown. In the figures 11 and 12, variations of Soret and Schmidt numbers are shown for the concentration of the fluid. It is observed that with the increase of Soret and Schmidt numbers, the concentration of the fluid decreases in the boundary layer gradually for Soret number but for Schmidt number it reduces rapidly. For the increase with the chemical reaction, the concentration distribution of the fluid decreases. This is shown in the figure 13.With the increase of viscosity i. e. the Eckert number (Ec), the mass transfer decreases. For the high viscosity i.e. large value of Ec, i.e. Ec = 0.7, the decrease in the boundary layer is sharp. This can be observed from the fig.14.As the radiation – convection parameter (R) increases the concentration of the fluid increases. This effect is shown in the fig.15.

7. CONCLUSIONS

The effects of viscosity and thermophoresis on a suddenly accelerated plate with variable approximated electronegativity with MHD fluid influenced by chemical reaction and radiation is considered. To simulate thermal radiation effects, the Rosseland diffusion flux model is used. The Governing equations are solved using the Finite difference method. The results are discussed through graphs and the conclusions are

- The velocity increases with the magnetic field (M), permeability (K), and the low inertial force (Re).
- The thermal buoyancy and Solutal buoyancy also increases the velocity.
- As a result of sudden movement of the plate, the decrease in electronegativity,results in the increase of velocity.
- The thermal distribution increases with the increase of Pr, Re, and viscosity.
- With the increase of radiation and large amounts of heat absorption, the temperature increases.
- With the increase of Sr and Sc, and with the rise in the chemical reaction the concentration distribution of the fluid decreases
- With increase of viscosity a sharp decrease is observed.
- With increase of radiation the concentration of the fluid is increased but it decreases in the boundary layer sharply

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