THERMAL RADIATION AND DUFOUR EFFECTS ON UNSTEADY MHD CASSON FLUID FLOW OVER A VERTICAL OSCILLATING PLATE

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***Abstract:** The present investigation deals with the study of an unsteady free convective Casson fluid flow over a vertical oscillating plate saturated with porous medium in the presence of heat source/sink, chemical reaction, thermal radiation and Dufour effect. The governing partial differential equations of the flow, heat and masss transfer are transformed into a system of ordinary differential equations. The resulting equations are solved analytically and the solutions for the velocity, temperature and concentration profiles are discussed with the support of graphs. It is observed that increasing values of Chemical reaction parameter depreciates the velocity and concentration profiles.*

***Index Terms:** MHD, Thermal radiation, Dufour, Casson fluid, heat source/sink.*

I. INTRODUCTION

The study of non-Newtonian fluids has a variety of applications in engineering and industry especially in extraction of crude oil from petroleum products. Casson fluid is a non-Newtonian fluid which exhibits yield stress. Human blood can also be treated as a Casson fluid due to the blood cells, chain structure and the substances contained like fibrinogen, protein etc,. Hence the Casson fluid has its own importance in scientific as well as in engineering areas. Kataria and Patel [1] analyzed the effects on MHD Casson fluid flow over an oscillating vertical plate in the presence of magnetic field. The study on MHD 3D-Casson fluid flow over a porous sheet was studied by Nadeem and Khan [2] Afikuzzaman et al. [3] discussed the unsteady MHD Casson fluid flow past a parallel plate with Hall current. The behavior of gyrotactic microorganisms in MHD flow of Casson fluid towards a rotating cone/plate with Soret and Dufour effects was discussed by Raju and Sandeep [4]. The behavior of chemical reaction, masss transfer and non-uniform heat source/sink on MHD Micropolar fluid towards a stretching/shrinking sheet with viscous dissipation was performed by Sandeep and Sulochana [5]. Raju and Srinivasa [6] investigated the study on MHD boundary layer flow of Casson fluid over an inclined plate in a porous medium in the presence of Chemical reaction and Thermal radiation effects. The researchers [7-11] focused their studies on analyzing the MHD flow of a Casson fluid over a stretching sheet in the presence of Thermal radiation, Chemical reaction, Soret and Dufour effects. Qasim and Noreen [12] presented the Heat transfer flow of a Casson fluid towards a permeable shrinking surface in viscous dissipation. The researchers [13-15] illustrated the Exact solutions for the flow of a Casson fluid due to stretching/shrinking surface with transpiration and thermal radiation effects. Shehzad et al. [16] carried out the study on MHD Casson fluid flow through a stretching sheet with suction.

The convective heat transfer phenomenon plays a major role in industries like steel, alloy casting, wire drawing, metallic insulation etc. Heat transfer characteristics of Casson fluid flow through an exponentially stretching sheet in presence of thermal radiation was discussed by Bhattacharyya [17]. Mustafa et al. [18] presented the study on Unsteady flow of a Casson fluid towards a flat plate. The effects of heat generation and radiation on MHD Casson fluid flow past a stretching sheet through porous medium was exhibited by Alsedais [19]. Mythili et al. [20] studied the characteristics of non-Newtonian fluid flow towards a vertical cone with porous medium. The researchers [21-22] carried out the results on Casson fluid flow past a stretching/shrinking sheet with radiation. Very recently, the researchers [23-31] studied the heat transfer behavior of magnetic flows by considering the various channels.

Motivated by the previously mentioned investigations on flow of non-Newtonian fluids and its vast applications in many industries, in the present paper , the study of unsteady, free convective Casson fluid flow over a vertical oscillating plate saturated with porous medium in the presence of non-uniform heat source/sink. The governing partial differential equations of the flow, heat and masss transfer are transformed into a system of ordinary differential equations. The resulting equations are solved analytically and the solutions for the velocity, temperature and concentration profiles are discussed with the support of graphs.

II. MATHEMATICAL ANALYSIS

Thermal radiation and masss transfer effects on unsteady MHD flow of a viscous incompressible fluid past along a vertical oscillating plate with variable temperature and also with variable masss diffusion in the presence of transverse applied magnetic field has been discussed.

- The x-axis is taken along the plate in the vertical upper direction and the y-axis is taken normal to the plate. It is assumed that the plate and fluid are at the same temperature T_∞ in the stationary condition with concentration level C_∞ at all the points.
- At time t>0, the plate is given an oscillatory motion in its own plane with velocity $U_o\cos(\omega t)$.
- At the same time the plate temperature is raised linearly with time and also masss is diffused from the plate linearly with time.
- A transverse magnetic field of uniform strength B_0 is assumed to be applied normal to the plate.
- The induced magnetic field and viscous dissipation is assumed to be negligible as the magnetic Reynolds number of the flow is taken to be very small.
- The fluid considered here is gray, absorbing/emitting radiation but a non-scattering medium.

Then by usual Boussinesq's approximation, the unsteady flow is governed by the following equations.

$$\frac{\partial u}{\partial t}=v\left(1+\frac{1}{\beta}\right)\frac{\partial^2 u}{\partial y^2}+g\beta\left(T-T_\infty\right)\cos\alpha+g\beta^*\left(C-C_\infty\right)\cos\alpha-\frac{u}{K}-\frac{\sigma B_0^2}{\rho}u \tag{1}$$

$$\frac{\partial T}{\partial t}=\frac{k}{\rho C_p}\frac{\partial^2 T}{\partial y^2}-\frac{1}{\rho C_p}\frac{\partial q_r}{\partial y}-\frac{Q_0}{\rho C_p}(T-T_\infty)+\frac{D_m K_T}{C_s C_p}\frac{\partial^2 C}{\partial y^2} \tag{2}$$

$$\frac{\partial C}{\partial t}=D\frac{\partial^2 C}{\partial y^2}-K_r\left(C-C_\infty\right) \tag{3}$$

The boundary conditions for the velocity, temperature and concentration fields are:

$$\left.\begin{array}{l} t\le 0: u=0,\ T=T_\infty, C=C_\infty, \\ t>0\begin{cases} u=U_0\cos(\omega t), v=0, T=T_\infty+\varepsilon\left(T_w-T_\infty\right)e^{nt}, C=C_\infty+\varepsilon\left(C_w-C_\infty\right)e^{nt} & at\ \ y=0 \\ u\to 0, v\to 0, T\to T_\infty, C\to C_\infty & as\ \ y\to\infty \end{cases}\end{array}\right\} \tag{4}$$

where u is the velocity in the x -direction, K is the permeability parameter, β is the volumetric coefficient of thermal expansion, β^* is the volumetric coefficient of expansion for concentration, ρ is the density, σ is the electrical conductivity, k - the thermal conductivity, g - the acceleration due to gravity, T is the temperature, T_ω - the fluid temperature at the plate, T_∞- the fluid temperature in the free stream, C is the species concentration, C_p is the specific heat at constant pressure, C_{∞}- Species concentration in the free stream, C_{ω}- Species concentration at the surface, D is the chemical molecular diffusivity, q_r is the radiative flux. The local radiant absorption for the case of an optically thin gray gas is expressed as

$$\frac{\partial q_r}{\partial y}=-4a^*\sigma\left(T_\infty^4-T^4\right) \tag{5}$$

where σ and a are the Stefan-Boltzmann constant and the Mean absorption coefficient, respectively. we assume that the temperature differences within the flow are sufficiently small so that T^4 can be expressed as a linear function of T after using Taylor's series to expand T^4 about the free stream temperature T and neglecting higher order terms. This results in the following approximation:

$$T^4\cong 4T_\infty^3 T-3T_\infty^4 \tag{6}$$

Using equations (5) and (6), from equation (2) becomes

$$\frac{\partial T}{\partial t}=\frac{k}{\rho C_p}\frac{\partial^2 T}{\partial y^2}-\frac{1}{\rho C_p}\left[16a^*\sigma T_\infty^3\left(T-T_\infty\right)\right]-\frac{Q_0}{\rho C_p}\left(T-T_\infty\right) \tag{7}$$

The following non-dimensionless quantities are introduced to transform equations (1), (3) and (7) into dimensionless form:

$$\left.\begin{array}{l} y^*=\dfrac{yu_0}{v}, u^*=\dfrac{u}{u_0},\ \theta=\dfrac{\left(T-T_\infty\right)}{\left(T_w-T_\infty\right)}, Sc=\dfrac{v}{D},\ \Pr=\dfrac{\mu C_p}{k}, M=\dfrac{\sigma B_0^2 v}{\rho u_0^2}, \\ R=\dfrac{16a^*\sigma v^2 T_\infty^3}{k u_0^2}, \omega=\dfrac{\omega v}{u_0^2}, Gm=\dfrac{g\beta^* v\left(C_w-C_\infty\right)}{u_0^3}, \phi=\dfrac{\left(C-C_\infty\right)}{\left(C_w-C_\infty\right)}, Gr=\dfrac{g\beta v\left(T_w-T_\infty\right)}{u_0^3}, \\ t^*=\dfrac{tu_0^2}{v}, K^*=\dfrac{Ku_0}{v^2}, Kr^*=\dfrac{Krv}{u_0^2}, S=\dfrac{Q_0}{\rho C_p}\left(T-T_\infty\right), Du=\dfrac{D_m k_T\left(C_w-C_\infty\right)}{C_s C_p v\left(T_w-T_\infty\right)} \end{array}\right\} \tag{8}$$

The basic field equations (1), (3) and (7) can be expressed in the non-dimensional form and dropping the stars (∗) as:

$$\frac{\partial u}{\partial t}=v\left(1+\frac{1}{\beta}\right)\frac{\partial^2 u}{\partial y^2}+Gr\theta\cos\alpha+Gm\phi\cos\alpha-\left(M+\frac{1}{K}\right)u \tag{9}$$

$$\frac{\partial\theta}{\partial t}=\frac{1}{\Pr}\frac{\partial^2 T}{\partial y^2}-\frac{R}{\Pr}\theta-S\theta+Du\frac{\partial^2 C}{\partial y^2} \tag{10}$$

$$\frac{\partial\phi}{\partial t}=\frac{1}{Sc}\frac{\partial^2\phi}{\partial y^2}-Kr\phi \tag{11}$$

The corresponding boundary conditions are:

$$\left.\begin{array}{ll} u=\cos(\omega t),\ \theta=t, \phi=t & at\ \ y=0 \\ u\to 0,\ \theta\to 0, \phi\to 0 & as\ \ y\to\infty \end{array}\right\} \tag{12}$$

Where M, K, G_r, G_m, P_r, K_r, S_c, R and S are the magnetic parameter, permeability parameter, Grashof number for heat transfer, Grashof number for masss transfer, Prandtl number, chemical reaction, Schmidt number , radiation parameter and heat source parameter respectively.

III. METHOD OF SOLUTION

$$u\left(y,t\right)=u_0\left(y\right)e^{i\omega t} \tag{13}$$

$$\theta(y,t)=\theta_0(y)e^{i\omega t} \tag{14}$$

$$\phi(y,t)=\phi_0(y)e^{i\omega t} \tag{15}$$

Substituting equations (13), (14) and (15) in equations (9), (10) and (11), we obtain:

$$u''_0-m_3^2u_0=-Gr\theta_0\cos\alpha-Gm\phi_0\cos\alpha \tag{16}$$

$$\theta_0''-m_2^2\theta_0=-Du\phi_0''\Pr \tag{17}$$

$$\phi''_0-m_1^2\phi_0=0 \tag{18}$$

Here the primes denote the differentiation with respect to y. The corresponding boundary conditions can be written as:

$$\left.\begin{array}{l} u_0=e^{-i\omega t}\cos(\omega t),\ \theta_0=te^{-i\omega t},\ \phi_0=te^{-i\omega t}\ \ at\ \ y=0,\\ u_0\to 0,\quad \theta_0\to 0,\quad \phi_0\to 0 \qquad\qquad as\ y\to\infty, \end{array}\right\} \tag{19}$$

The analytical solutions of equations (16) - (18) with satisfying boundary conditions (19) are given by

$$u_0(y)=\left\{\left[\cos(\omega t)-k_2-k_5\right]e^{-m_3y}+(k_2e^{-m_2y}+k_5e^{-m_1y})\right\}e^{-i\omega t} \tag{20}$$

$$\theta_0(y)=(t-k_1)e^{-m_2y}e^{-i\omega t}+k_1e^{-m_1y}e^{-i\omega t} \tag{21}$$

$$\phi_0(y)=\left(te^{-m_1y}\right)e^{-i\omega t} \tag{22}$$

where

$$m_1=\sqrt{(Kr+i\omega)Sc},\ m_2=\sqrt{R+(S+i\omega)\Pr},\ m_3=\sqrt{\frac{N+i\omega}{B}},\ N=M+\frac{1}{K},$$

$$k_1=\frac{-Du\Pr m_1^2t}{m_1^2-m_2^2},\ k_2=\frac{-Gr\cos\alpha(t-k_1)}{B(m_1^2-m_3^2)},\ k_3=\frac{-Gr\cos\alpha k_1}{B(m_1^2-m_3^2)},$$

$$k_4=\frac{-Gm\cos\alpha t}{B(m_1^2-m_3^2)},\ k_5=k_3+k_4,\ k_6=\cos\omega t-k_2-k_5.$$

In view of the above equations, the velocity, temperature and concentration distributions in the boundary layer become

$$u(y,t)=\left[\cos(\omega t)-k_2-k_5\right]e^{-m_3y}+(k_2e^{-m_2y}+k_5e^{-m_1y}) \tag{23}$$

$$\theta(y,t)=(t-k_1)e^{-m_2y}+k_1e^{-m_1y} \tag{24}$$

$$\phi(y,t)=\left(te^{-m_1y}\right) \tag{25}$$

IV. RESULTS AND DISCUSSION

The behavior of various governing parameters on the physical quantities are computed and represented in Figures below and discussed in detail. For numerical results we used M=1, G_{m}=5, Gr=5, Pr=0.71, Sc=0.5, R=1, t=1, K=0.5, S=0.5, Kr=0.5,Du=0.3,i=1,ω=1,β=0.80. These values are treated as common throughout the study except varied values in respective figures.

Figs.1and 4 respectively displays the influence of Prandtl number and Chemical reaction parameters on the velocity profiles of the flow. It is evident that an increase in the Prandtl number and Chemical reaction parameters depreciates the velocity profiles of the flow. Figs.2 and 3 illustrates the effects of Grashof number and Grashof number for mass transfer parameters on the velocity profiles of the flow. It is clear that increase in the Grashof number and Grashof number for mass transfer parameters enhances velocity profiles of the flow.

Figs. 5 and 6 have been plotted to demonstrate the effects of Schmidt number and Permeability parameter on the velocity profiles. It is observed that as the Schmidt number and Permeability parameter increases the velocity of the fluid increases. Fig.7 depict to analyze the various values of Dufour effect parameter. It is noticed that an increasing values of Dufour effect parameter increases the velocity profiles. Figs.8,10,11 and 12 displayed to show the influence of Radiation parameter, Heat source parameter, different values of α and time t on the velocity profiles. It is observed that a rising values of Radiation parameter, Heat source parameter, different values of α and time t depreciates the velocity profiles of the flow.

Fig.9 exhibit the effects of magnetic field parameter on the velocity profiles. It is evident the velocity declines with rise in magnetic field parameter. But reverse results has been observed with an increase in the magnetic field parameter. The magnetic field opposes the rate of transportation. Generally, an increase in the magnetic field results a strong reduction in the dimensionless velocity. This is due to the fact that the magnetic field introduces a retarding body force known as Lorentz force. We observed that the Lorentz force helps to enhance the flow.

Figs. 13,14 and 16 depicted to examine the effects of Prandtl number, Radiation parameter and Heat source parameters on the temperature profiles. It is evident from figures that increase in Prandtl number, Radiation parameter and Heat source parameters decreases the temperature profiles of the fluid. Fig.15 shows the various values of Dufour effect parameter on the temperature profiles. It is clear that increase in the Dufour effect parameter increases the temperature profiles.

Figs. 17 and 18 illustrates the effects of Schmidt number and Chemical reaction parameters on the concentration profiles. It is seen from the figures that the rising values of Schmidt number and Chemical reaction parameters decays the concentration profiles.

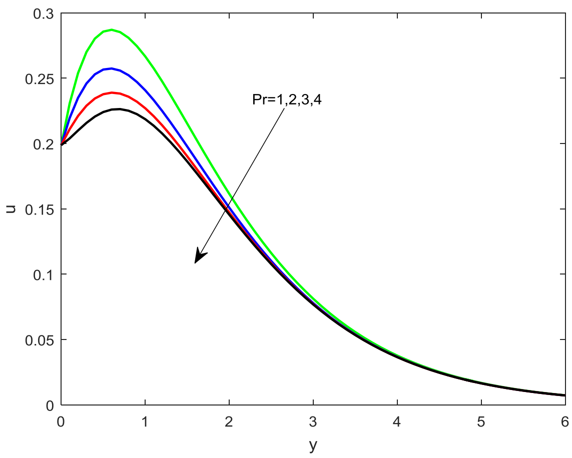

Fig.1. Velocity profiles for different values of Pr.

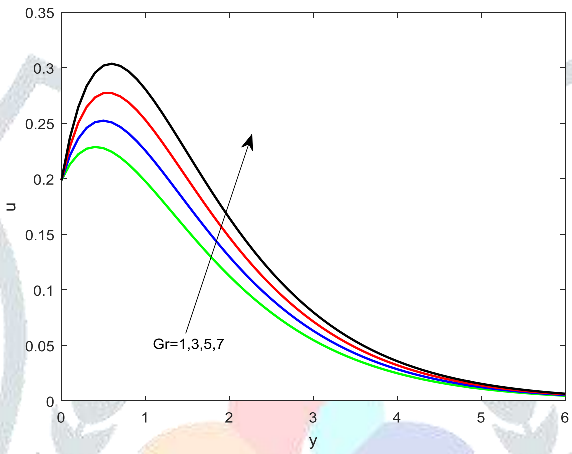

Fig.2. Velocity profiles for different values of Gr.

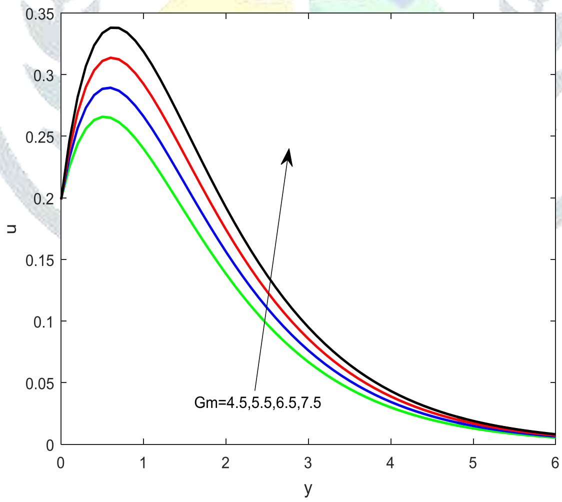

Fig.3. Velocity profiles for different values of Gm.

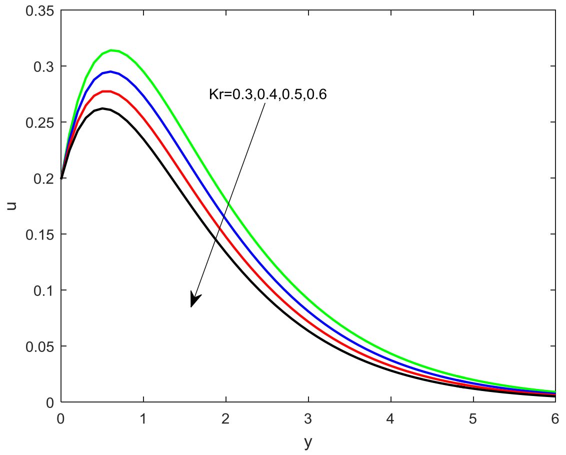

Fig.4. Velocity profiles for different values of Kr.

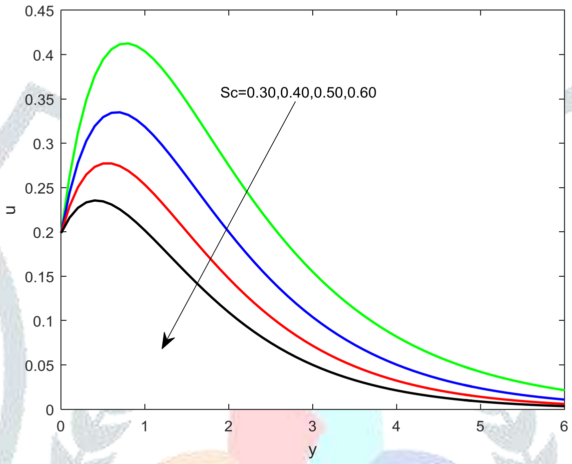

Fig.5. Velocity profiles for different values of Sc.

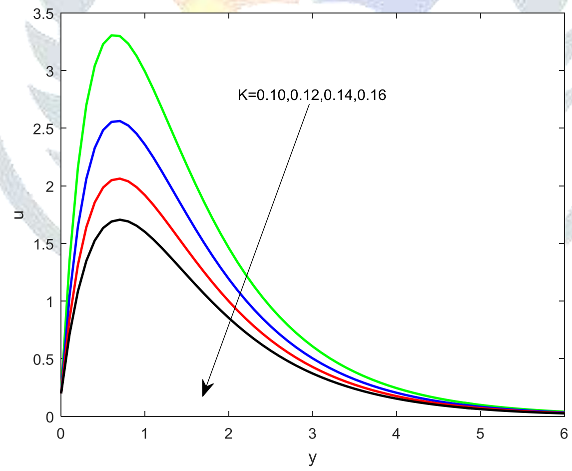

Fig.6. Velocity profiles for different values of K.

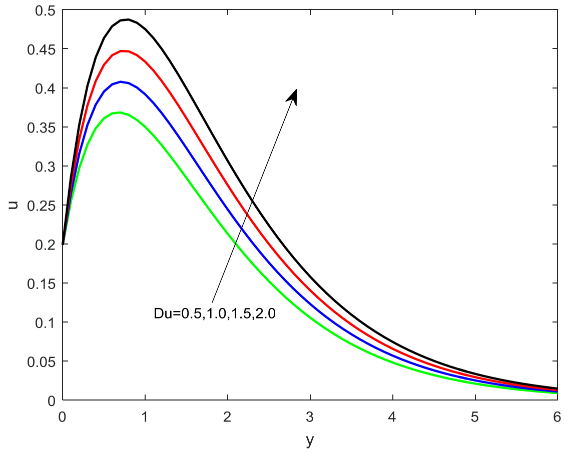

Fig.7. Velocity profiles for different values of Du.

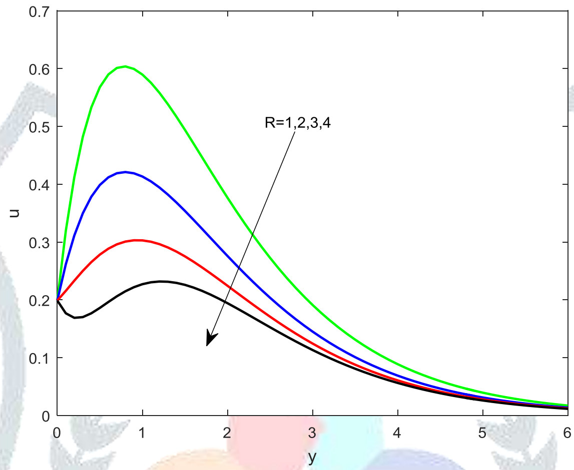

Fig.8. Velocity profiles for different values of R.

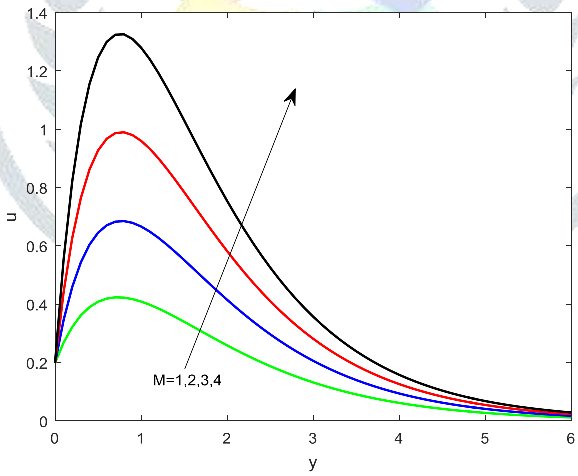

Fig.9. Velocity profiles for different values of M.

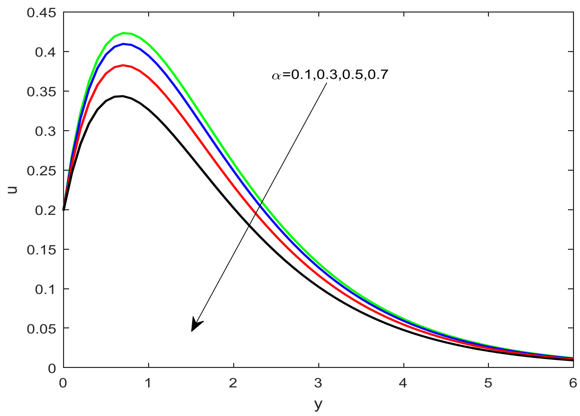

Fig.10. Velocity profiles for different values of α.

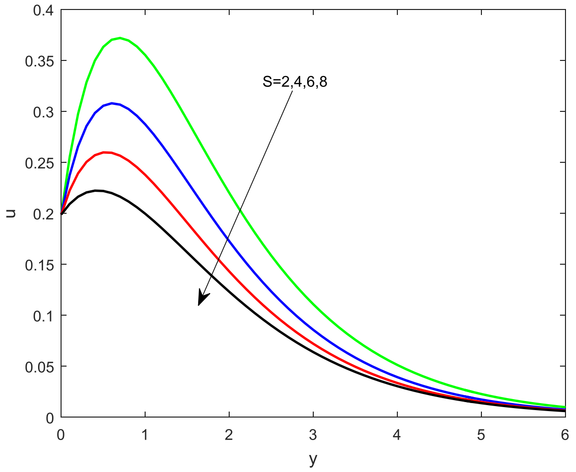

Fig.11. Velocity profiles for different values of S.

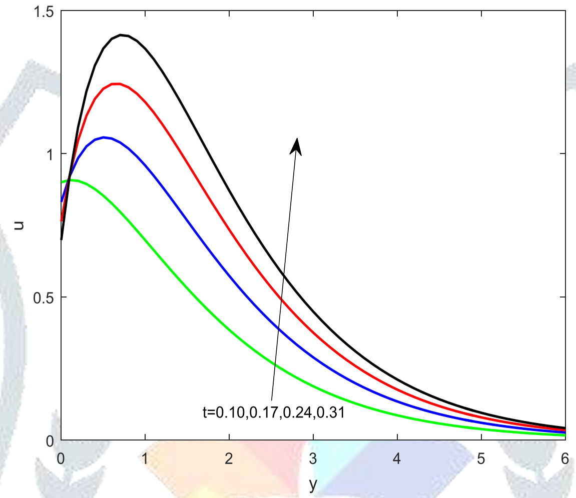

Fig.12. Velocity profiles for different values of t.

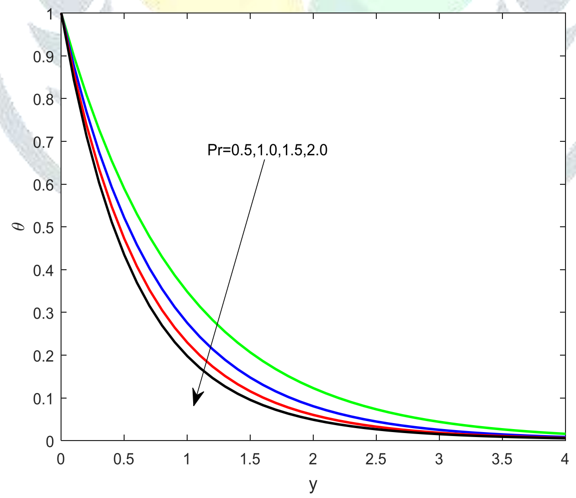

Fig.13. Temperature profiles for different values of Pr.

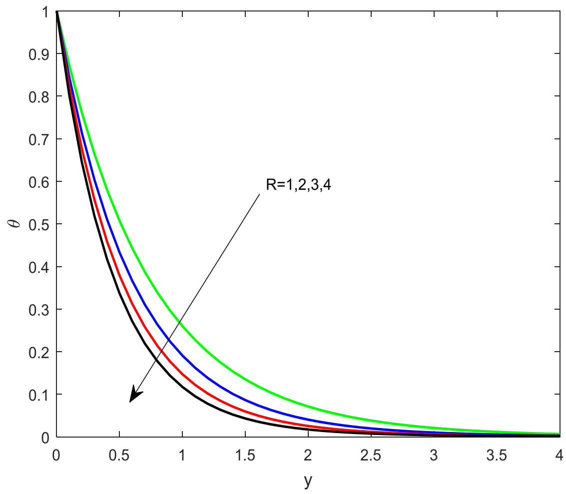

Fig.14. Temperature profiles for different values of R.

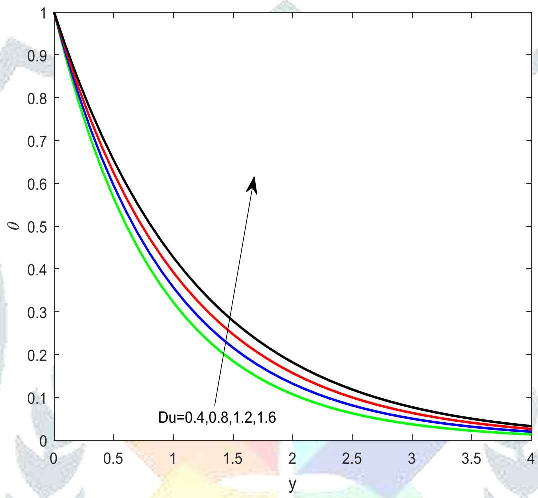

Fig.15. Temperature profiles for different values of Du.

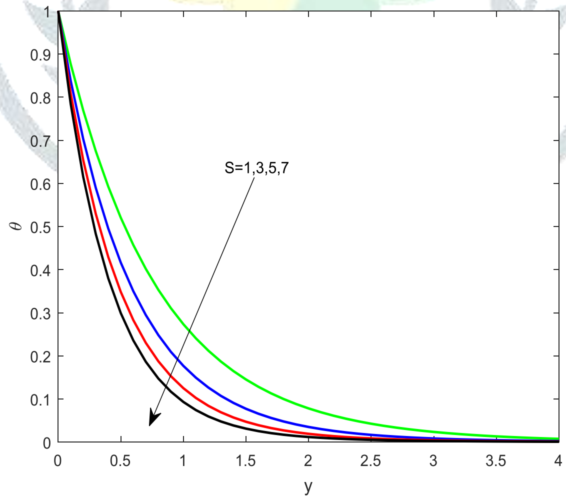

Fig.16. Temperature profiles for different values of S.

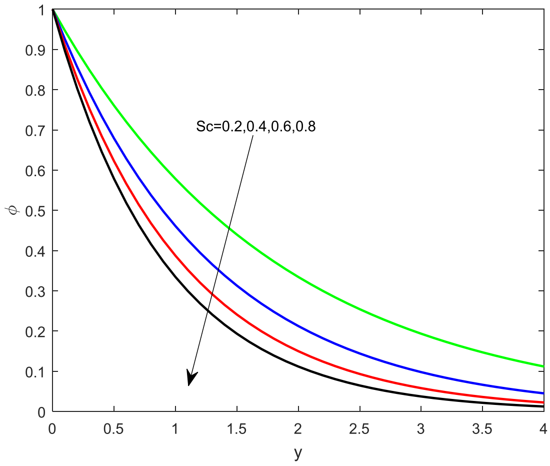

Fig.17. Concentration profiles for different values of Sc.

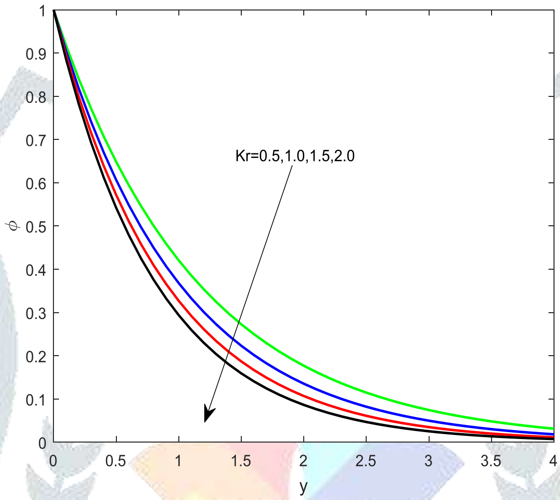

Fig.18. Concentration profiles for different values of Kr.

V. CONCLUSIONS

Heat transfer behavior of the Magnetohydrodynamic flow of a Casson fluid over a vertical oscillating plate in the presence of non-uniform heat source/sink is investigated. The governing partial differential equations are transformed as non-dimensional equations using suitable transformation and resulting equations are solved using Perturbation technique. The effect of non-dimensional parameters namely thermal radiation, heat source/sink, Grashof number and magnetic field parameter on the flow and heat transfer is analyzed for non- Newtonian Casson fluid case. Observations of the present study are as follows:

- Momentum and thermal boundary layers of Casson fluid are non-uniform.
- The influence of buoyancy and thermal radiation on non-Newtonian fluids is not uniform.
- Increasing the Magnetic field parameter enhance the flow field.
- Rising the heat source parameter and thermal radiation reduces the heat transfer rate.
- Increasing the Schmidt number and Chemical reaction parameter decays the concentration profiles.

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