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Joule Heating Influence On Mhd Casson Fluid Over A Vertical Porous Plate In The Presence Of Thermal Diffusion And Chemical Reaction

[1]S. Harinath Reddy [1]P. Chandra Reddy [1]M.C. Raju [2]E. Keshava Reddy
[1]*Department of Mathematics, Annamacharya Institute of Technology and Sciences (Autonomous), Rajampet-516126, A.P., India.*
[2]*Department of Mathematics, JNTUA College of Engineering, Ananthapur, A.P., India.*
Email: harinath.singamala@gmail.com [1] chandramsc01@gmail.com [1], mcrmaths@yahoo.co.in[1],
keshava_e@rediffmail.com[1]

Abstract- This paper reveals a theroritical analysis on the influence of Joule heating influence on MHD Casson fluid flow past a vertical plate. The impact of porous medium, thermal radiation, thermal diffusion and chemical reaction are also taken into consideration. The non-dimensional governing equations are solved by applying finite difference scheme and the variations in velocity, temperature and concentration are explained with the numerical data presented in the form of graphs. Skin friction, rate of heat transfer and rate of mass transfer of the flow are studied by using tabulated values. The influence of Eckert number leads to enhance the velocity as well as temperature. The concentration of the fluid decreases under the impact of chemical reaction.

Keywords: Casson fluid, Joul heating, porous medium, thermal radiation, thermal diffusion and chemical reaction.

1. INTRODUCTION

The non-Newtonian fluid model is one of the Casson fluid models which were introduced by Casson in 1995. It is based on the model structure and its behavior of both liquid and solid of a two-phase suspension that exhibits yield stress. Casson fluid is well known for shear thinning liquid which is formed to an infinite viscosity at zero, if the shear stress is less than the yield stress is applied to the fluid; it's like a solid, if the shear stress larger than yield stress is applied, and its starts to move. Examples of Casson fluid are as follows: Jelly, tomato sauce, honey, soup, concentrated fruit juices. Human blood also treated as Casson fluid. Pramanik [2] investigated Casson fluid flow and heat transfer past an exponentially porous stretching surface in presence of thermal radiation. Qasim, and S. Noreen [3] studied heat transfer in boundary layer flow in a Casson fluid over permeable shrinking sheet with viscous dissipation. Das et. al. [4] who considered Newtonian heating effect on unsteady hydromagnetic Casson fluid flow past a flat plate with heat and mass transfer. Ullah et al. [5] analyzed hydromagnetic Falknerskan flow of Casson fluid past a moving wedge with heat transfer. Mukhopadhyay and Mandal [6] established the boundary layer flow and heat transfer of a Casson fluid past a symmetric porous wedge with surface heat flux. Makanda et al. [7] studied the effect of radiation on MHD free convection of a Casson fluid from a horizontal circular cylinder with partial slip in non-Darcy porous medium with viscous dissipation. Sidha reddy et al. [8] considered effects of radiation on MHD radiating fluid embedded in porous medium. Reddy et al. [9] investigated the effects of Joule heating and radiation absorption effects on MHD convective and chemically reactive flow past a porous plate. Loganathan and Sivapoornapriya [10] have analyzed Ohmic heating and viscous dissipation effects over a vertical plate in the presence of porous medium. Goyal and Sunitha [11] studied the effect of MHD free convective flow over a vertical porous surface with Ohmic heating, thermal radiation and chemical reaction. Chen [12] have considered combined heat and mass transfer in MHD free convection from a vertical surface with Ohmic heating and viscous dissipation. Umamaheswar et al. [13] have considered unsteady MHD free convective visco-elastic fluid flow bounded by an infinite inclined porous plate in the presence of heat source, viscous dissipation and Ohmic heating. Rama mohan et al. [14] analyzed thermal diffusion and Joule heating effects on magnetohydrodynamics and heat and mass transfer effects. Chandrasekhar et al. [15] investigated about the effects of Joule heating on MHD free convective flow along a moving vertical plate in porous medium.

The driving potentials and fluxes are associated with each other in a moving fluid in the existence of thermal and solutal buoyancy. The studies related to this phenomenon experienced that the energy flux can be produced by concentration gradients and also temperature gradients. The energy flux caused by a concentration gradient is known as Dufour (diffusion-thermo) effect. In addition to this process, mass flux can be generated by temperature gradients and this defines the Soret (thermal-diffusion) effect. Reddy et al. [16] to [19] discussed thermal and solutal effect on MHD boundary layer flow of a visco-elastic fluid past a porous plate for different types of fluids. Ananda reddy et al. [20] considered radiation and Dufour effects on laminar flow of a rotating fluid past a porous plate in conducting field. Srinivasacharya et al. [21] investigated about the Soret and Dufour effects on mixed convection along a vertical wavy surface in a porous medium with variable properties. Narayana et al. [22] analyzed the Soret and Dufour effects on free convection heat and mass transfer from a horizontal flat plate in a Darcy porous medium. Rahman and Samad et al. [23] studied Dufour and Soret effects on unsteady MHD free convection mass transfer flow past a vertical porous plate in a porous medium. Maleque [24] analyzed Soret and Dufour effects on unsteady MHD free convective heat and mass transfer flow due to a rotating disk. Mohyuddin et al. [24] considered a numerical study of thermo-diffusion and diffusion-thermo and chemical reaction effects on flow of a micropolar fluid in an asymmetric channel with dilating and contracting permeable wall. Hayat and Shehzad [26] put an effect on the study of Soret and Dufour effects on MHD flow of Casson fluid.

2. FORMULATION OF THE PROBLEM:

Consider a two-dimensional unsteady Casson fluid of an incompressible, viscous, electrically conducting fluid over a vertical porous plate moving with constant velocity with the radiation and chemical reaction in the presence of Soret effect and Joule heating is considered. The flow of an incompressible viscous fluid passing a flat sheet coinciding with plane y = 0.We select the Cartesian coordinate system such that the x – axis to be taken parallel to the surface and y axis is perpendicular to the surface. The fluid occupies a half space y>0. The flow is subjected to a constant applied magnetic field B_0 in the y-direction. The magnetic Reynolds number is considered to be very small so that the induced magnetic field is negligible in comparison to the applied magnetic field. The surface temperature of the plate oscillates with small amplitude about a non-uniform mean temperature. The fluid is assumed to have constant properties except for the influence of the density variations with temperature and concentration which are considered only in the body force term. The temperature of the plate oscillates with little amplitude about a non-uniform temperature.

The rheological equation of state for an isotropic flow of a Casson fluid can be expressed as:

$$\tau_{ij} = \begin{cases} 2\left(\dfrac{\mu_B + P_y}{\sqrt{2\pi}}\right)e_{ij}, & \pi > \pi_c \\ 2\left(\dfrac{\mu_B + P_y}{\sqrt{2\pi_c}}\right)e_{ij}, & \pi < \pi_c \end{cases} \tag{1}$$

$$\frac{\partial u^*}{\partial t^*} = \left(1+\frac{1}{\gamma}\right)\frac{\partial^2 u^*}{\partial y^{*2}} + g\beta\left(T^* - T^*_\infty\right) + g\beta*\left(C^* - C^*_\infty\right) - \frac{\sigma B_0^2}{\rho}u^* - \frac{\nu}{K^*}u^* \tag{2}$$

$$\frac{\partial T^*}{\partial t^*} = \frac{\kappa}{\rho Cp}\frac{\partial^2 T^*}{\partial y^{*2}} + \frac{\sigma B_0^2}{\rho Cp}u^{*2} + \frac{\nu}{Cp}\left(\frac{\partial u^*}{\partial y^*}\right)^2 + \frac{Q_0}{\rho Cp}\left(T^* - T^*_\infty\right) - \frac{1}{\rho Cp}\frac{\partial q_r^*}{\partial y^*} \tag{3}$$

$$\frac{\partial C^*}{\partial t^*} = D_M\frac{\partial^2 C^*}{\partial y^{*2}} - K_r^*\left(C^* - C^*_\infty\right) + \frac{D_T K_t}{T_m}\frac{\partial^2 T^*}{\partial y^{*2}} \tag{4}$$

Eq. (2),(3) and (4) refers momentum equation, energy and species equation respectively where u is the velocity of the fluid, γ is Casson parameter, Q_0 is the heat source/sink parameter, D_M is the molecular diffusivity, k is thermal conductivity, C is mass concentration, t is time, ν is the kinematics viscosity, g is the gravitational constant, β and β* are the thermal expansions of fluid and concentration, ρ is density, Cp is the specific heat capacity at constant pressure, D_T is coefficient of mass diffusivity, K_t is thermal diffusion ratio, T_m mean fluid temperature, T_∞ free stream temperature of the surrounding fluid, C_∞ free stream concentration, T fluid temperature, C fluid concentration, q_r is the radiative flux, B_0 is the magnetic field and K_r is the chemical reaction rate constant.

Under the above assumptions the physical variables are functions of y and t. The boundary conditions for the velocity, temperature and concentration fields are:

$$\begin{aligned} &u^* = U, \quad T^* = T_\infty^* + \varepsilon\left(T_w^\infty - T_\infty^*\right)e^{n^*t^*}, \\ &C^* = C_\infty^* + \varepsilon\left(C_w^* - C_\infty^*\right)e^{n^*t^*} \text{ at } y^* = 0 \\ &u^* \to 0, \quad T^* \to T_\infty^*, \\ &C^* \to C_\infty^*, \text{ as } y^* \to \infty \end{aligned} \tag{5}$$

Introducing the non-dimensional quantities with thermal radiation heat flux gradient expressed and we assume that the temperature differences within the flow are sufficiently small so that T^*can be expressed as a linear function of T^* after using Taylor's series to expand T^{*4}about the free stream temperature $T_\infty^*$and neglecting higher-order terms. This results in the following approximation.

$$\frac{\partial {q_r}^*}{\partial y^*} = -4a^*\sigma^*(T_\infty^* - T^{*4}) \tag{6}$$

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

The following dimensionless quantities are introduced

$$\begin{aligned} &u=\frac{u^*}{U}, \quad y=\frac{Uy^*}{\nu}, \quad t=\frac{Ut^*}{\nu}, \quad \theta = \frac{T^*-T_\infty^*}{T_W^*-T_\infty^*}, \\ &C = \frac{C^*-C_\infty^*}{C_W^*-C_\infty^*}, \quad Q=\frac{Q_0\nu}{\rho C_p U^2}, \quad K=\frac{K^* u_0^2}{\nu^2} \\ &P_r=\frac{\mu C_p}{k}, \quad S_c=\frac{\nu}{D}, \quad M=\frac{\sigma B_0^2 \nu}{\rho U^2}, \quad G_r=\frac{\nu\beta g(T_W^*-T_\infty^*)}{U^2}, \\ &G_c = \frac{\nu\beta^* g(C_W^*-C_\infty^*)}{U^3} \quad K_r=\frac{K_r^*\nu}{U_0^2}, \\ &R=\frac{16a^*\nu\sigma^* T_\infty^{*3}}{\rho C_p U^2}, \quad E = \frac{U_0^2}{\rho C_p (T^* - T_\infty^*)} \\ &\mu = \nu\rho, \quad s_o = \frac{D_\varepsilon K_t U^2}{T_m \nu^2}(T_w^* - T_\infty^*) \end{aligned} \tag{7}$$

The thermal radiation heat flux gradient may be expressed as follows

$$-\frac{\partial q_r}{\partial y^*}=4a\sigma^*(T_\infty^* - T^{*4}) \tag{8}$$

Considering the temperature difference by assumption within the flow are sufficiently small such that T^{*4}may be expressed as a linear function of the temperature. This is attained by expanding inT^{*4}Taylor's series about $T^{*4}$and ignoring higher order terms

$$T^{*4} \cong 4T_\infty^{*3}T^* - 3T_\infty^{*4} \tag{9}$$

Substituting the dimensionless variables (7) into (2) to (4) and using equations (8) and (9), reduce to the following dimensionless form

$$\frac{\partial u}{\partial t}=\left(1+\frac{1}{\gamma}\right)\frac{\partial^2 u}{\partial y^2} + G_r\theta + G_c C - \left(M+\frac{1}{K}\right)u \tag{10}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{P_r}\frac{\partial^2 \theta}{\partial y^2} - R\theta + Q\theta + MEu^2 + \left(\frac{\partial u}{\partial y}\right)^2 \tag{11}$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} - KrC + So\frac{\partial^2 \theta}{\partial y^2} \tag{12}$$

The corresponding boundary conditions are

$$\begin{aligned} &u = 1, \; \theta = 1 + \varepsilon e^{nt}, \\ &C = 1 + \varepsilon e^{nt} \text{ at } y = 0 \\ &u \to 0, \; \theta \to 0, \\ &C \to 0, \text{ as } y \to \infty \end{aligned} \tag{13}$$

where $G_r$is thermal Grashof number,$P_r$is the Prandtl number, $k_r$is the chemical reaction parameter, R is the thermal radiation conduction number, M is Hartmann number, $G_c$is the mass Grashof number, Q is the heat source parameter, E is the Eckert number and So is the Soret number.

3. METHOD OF SOLUTION:

Equations (10)-(12) are linear partial differential equations and are to be solved with the initial and boundary conditions (13). In fact the exact solution is not possible for this set of equations and hence we solve these equations by finite-difference method. The equivalent finite difference schemes of equations for (10)-(12) are as follows:

$$\frac{u_{i,j+1} - u_{i,j}}{\Delta t} = \left(1+\frac{1}{\gamma}\right)\frac{u_{i-1,j} - 2u_{i,j} + u_{i+1,j}}{(\Delta y)^2} \\ Gr\,\theta_{i,j} + Gc\,C_{i,j} + -M\,u_{i,j} - \frac{1}{K}u_{i,j} \tag{14}$$

$$\frac{\theta_{i,j+1}-\theta_{i,j}}{\Delta t}=\frac{1}{\Pr}\frac{\theta_{i-1,j}-2\theta_{i,j}+\theta_{i+1,j}}{(\Delta y)^2}+Q\theta_{i,j} - R\theta_{i,j}+Df\frac{C_{i-1,j}-2C_{i,j}+C_{i+1,j}}{(\Delta y)^2} \quad (15)$$

$$\frac{C_{i,j+1}-C_{i,j}}{\Delta t}=\frac{1}{Sc}\frac{C_{i-1,j}-2C_{i,j}+C_{i+1,j}}{(\Delta y)^2}+S_0\frac{\theta_{i-1,j}-2\theta_{i,j}+\theta_{i+1,j}}{(\Delta y)^2}-KrC_{i,j} \quad (16)$$

Here, the suffix i corresponds to y and j to time. The mesh system is divided by taking $\Delta y = 0.1$. From the initial condition in (13), we have the following equivalent:

$$u(i,0)=0,\ \theta(i,0)=0, \quad C(i,0)=0\ \ for\ all\ i \quad (17)$$

The boundary conditions from (13) are expressed in finite-difference form as follows

$$\begin{aligned} &u(0,j)=at, \theta(0,j)=1+\varepsilon e^{nt}, \\ &C(0,j)=1+\varepsilon e^{nt}\ \ for\ all\ j \\ &u(i_{\max},j)=0, \theta(i_{\max},j)=0, \\ &C(i_{\max},j)=0\ \ for\ all\ j \end{aligned} \quad (18)$$

(Here i_{max} was taken as 200)

The velocity at the end of time step viz, u(i, j+1)(i=1,200) is computed from (14) in terms of velocity, temperature and concentration at points on the earlier time-step. After that θ (i, j +1) is computed from (15) and then C (i, j +1) is computed from (16). The procedure is repeated until t = 0.5 (i.e. j = 500). During computation Δt was chosen as 0.001.

Skin-friction: The skin-friction in non-dimensional form is given by the relation

$$\tau=-\left(\frac{du}{dy}\right)_{y=0}$$

Rate of heat transfer: The dimensionless rate of heat transfer in terms of Nusselt number is given by

$$Nu=-\left(\frac{d\theta}{dy}\right)_{y=0}$$

Rate of mass transfer: The dimensionless rate of mass transfer in terms of Sherwood number is given by

$$Sh=-\left(\frac{dC}{dy}\right)_{y=0}$$

4. RESULTS AND DISCUSSION:

Variations in the fluid velocity are presented in the figures 1 to 6. Figures 1 and 2exhibit the velocity profiles for different values of Gr and Gc. It is noticed from the figures that the velocity of the fluid increases for raising values of Gr and Gc. Fig. 3 shows the effect of Casson parameter on velocity. The velocity of the fluid decreases when the Casson parameter values are increased. The velocity of the fluid decreases for increasing values of M. It is evident in the Fig. 4. Fig. 5 displays the effect of K on velocity. The velocity of the fluid increases for different values of porosity parameter. The velocity of the fluid slightly increases for increasing values of E, it is evident in the figure 6. Temperature variations under the effect of different parameters are presented in the figures 7 to 11. Temperature variations under the effect Pr is presented in Fig. 7. The temperature of the fluid decreases when Prandtl number values are increased. The temperature of the fluid increased for raising values of Q, it is evident in the figure 8. Variations in temperature under the effect of R is shown in the figure 9. From these figure it is noticed that the temperature of the fluid decreases for increasing values of R. The temperature of the fluid decreased for different values of M and it is shown in the Fig. 10. Fig.11 reveals the effect of E on temperature. From these figure it is noticed that the temperature of the fluid increases for raising values of E. The concentration of the fluid decreases for increasing values of Sc. It is evident in the Fig. 12. The increasing values of S_o effects to increase the concentration, it is observed in Fig. 13. The effect of Kr on concentration is shown in the Fig. 14. Concentration of the fluid decreases for increasing values of Kr. Table. 1 reveals that skin friction values are increased for increasing values of Q, Kr, Sc, γ, Pr and M but it shows reverse trend in the case of E, S_o, Gr and Gc. Nusselt number and Sherwood number values are increased for increasing values of E, Q, Kr and Sc but both are decreasing for raising values of Q, E and S_o.

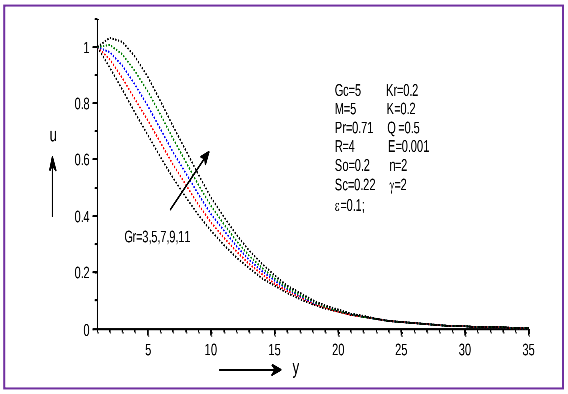

Fig. 1: variations in velocity with the influence of Gr.

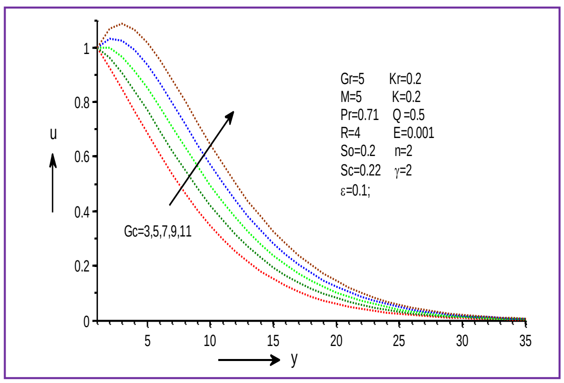

Fig.2 : variations in velocity under the effect of Gc.

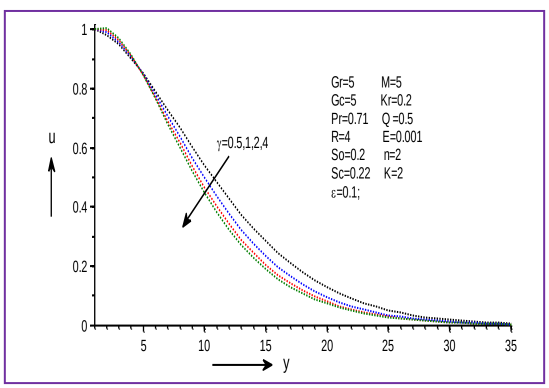

Fig.3 : Effect of γ on velocity.

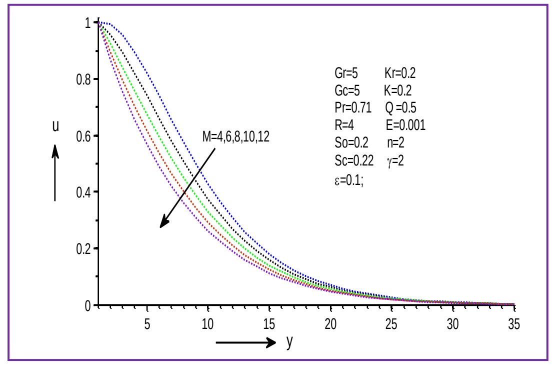

Fig.4: Fluctuations in velocity with the effect of M.

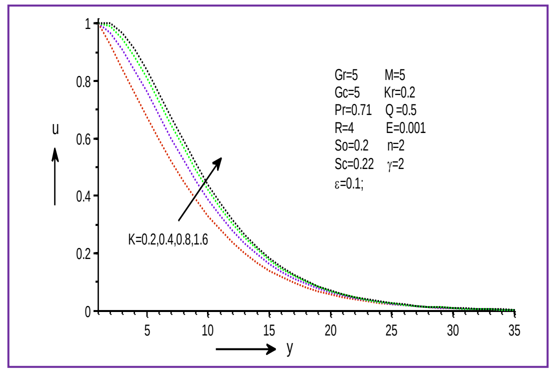

Fig. 5: Effect of K on velocity profiles.

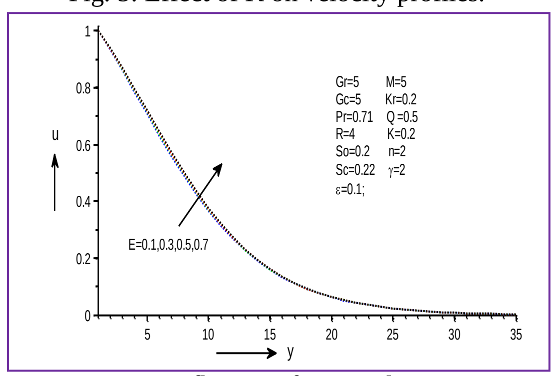

Fig.6: Influence of E on velocity.

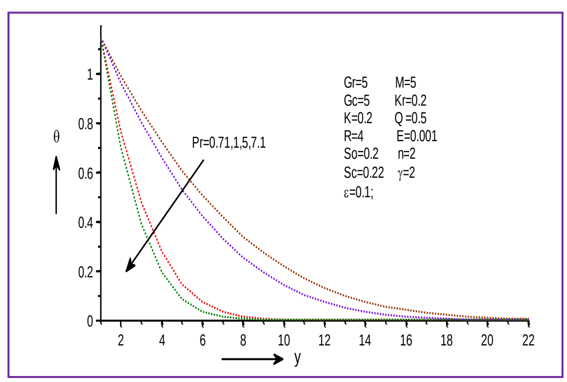

Fig.7: Effect of Pr on temperature.

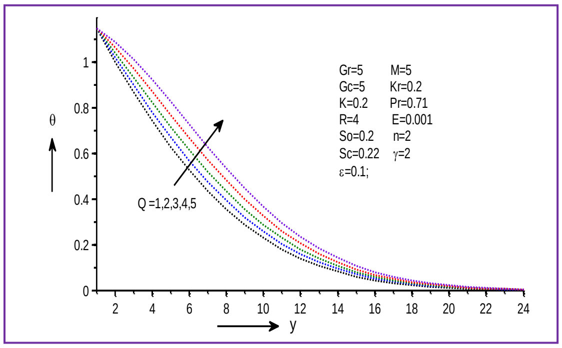

Fig.8: Influence of Q on temperature.

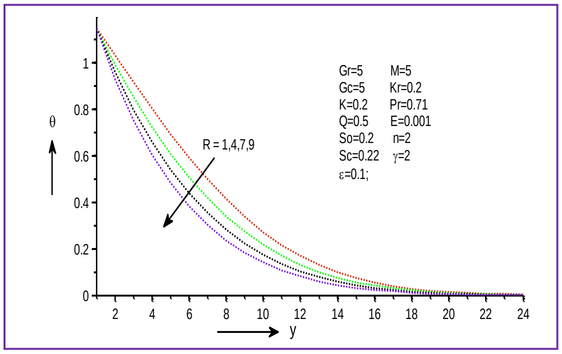

Fig.9 : Effect of R on temperature.

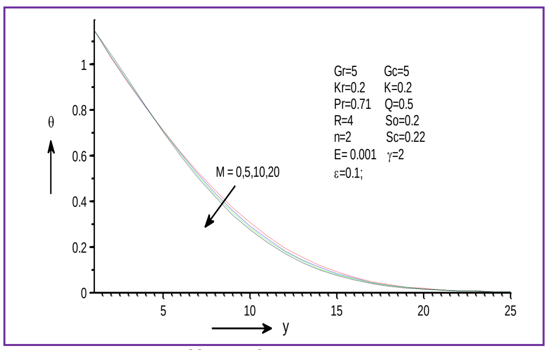

Fig. 10: Effect of M on temperature.

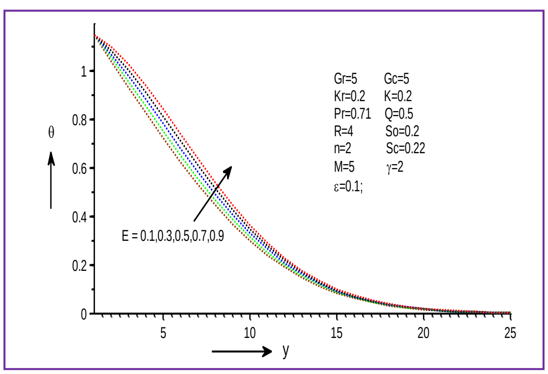

Fig. 11: Influence of E on temperature.

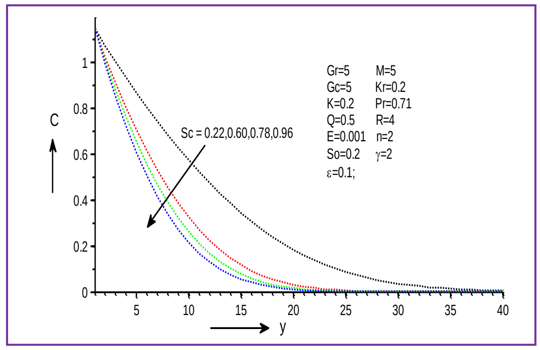

Fig. 12: Effect of Sc on Concentration.

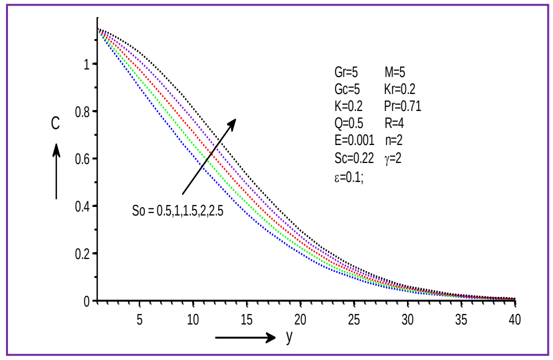

Fig. 13: Effect of So on concentration

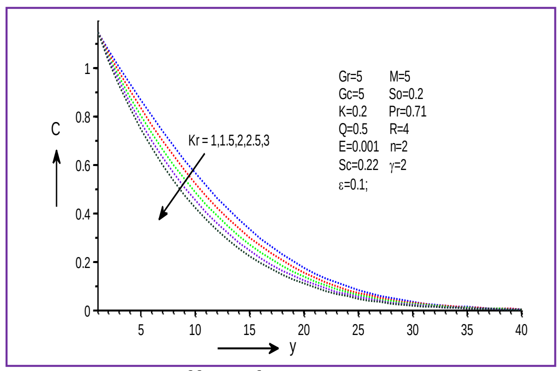

Fig. 14: Effect of Kr on concentration.

5. CONCLUSION

An analysis of joule heating influence on MHD casson fluid over a vertical porous plate in the presence of thermal diffusion and chemical reaction has been presented. The flowing are the some important finding of the present study.

1. The velocity of the fluid increased for increasing values of Gr, Gc K and E. But it shows the reverse trend in the case γ and M.

2. The temperature of the fluid increased for raising values of Q, E and it decreases for increasing values of Pr, R and M.
3. The concentration of the fluid increased for increasing value of S_o and it is decreases for different values of Sc, Kr.
4. Skin friction values are increased for increasing values of Q, Kr, Sc, γ, Pr and M but it shows reverse trend in the case of E, S_o, Gr and Gc.
5. Nusselt number and Sherwood number values are increased for increasing values of E, Q, Kr and Sc but both are decreasing for raising values of Q, E and S_o.

Table: 1 Numerical values for Skin friction, Nusselt number and Sherwood number for different values of parameters.

E	**Q**	**Kr**	**So**	**Sc**	**Gr**	**Gc**	γ	**Pr**	**M**	**T**	**Nu**	**Sh**
0.2	0.1	0.1	0.5	0.6	10	5	0.5	0.71	0.2	-3.0959	0.2704	1.8735
0.4										-3.3028	0.4659	0.9626
0.6										-3.6956	0.6006	0.8942
	0.2									-4.5626	0.0042	0.8163
	0.4									-3.9068	0.0038	0.9877
	0.6									-3.5039	0.0034	1.0178
		0.2								-3.5538	0.2704	0.5995
		0.4								-3.3939	0.2704	0.8391
		0.6								-3.2945	0.2704	0.9322
			0.6							-3.7059	0.2704	2.5848
			0.8							-3.7173	0.2704	2.2962
			1							-3.7286	0.2704	2.1076
				0.22						-3.8131	0.2704	0.5300
				0.6						-3.6949	0.2704	1.2733
				0.78						-3.6585	0.2704	1.6793
					1					-1.0154	0.2704	1.8735
					5					-2.2066	0.2704	1.8735
					10					-3.6948	0.2704	1.8735
						1				-2.4358	0.2704	1.8735
						5				-3.6948	0.2704	1.8735
						10				-5.2687	0.2704	1.8735
							0.2			-3.5263	0.2704	1.8735
							0.4			-3.3401	0.2704	1.8735
							0.6			-2.9108	0.2704	1.8735
								0.71		-3.6947	0.2704	1.8735
								1		-3.5810	0.3213	1.1881
								7.1		-2.8084	0.8500	0.8055
									1	-3.6945	0.2704	1.8735
									3	-3.5972	0.2704	1.8735
									5	-3.5045	0.2704	1.8735

REFERRENCES

[1] Casson, N. A Flow Equation for Pigment-Oil Suspensions of the Printing Ink Type. In: Mill, C.C., Ed., Rheology of Disperse Systems, Pergamon Press, Oxford, pp.84-104, 1959

[2] S. Pramanik, Casson fluid flow and heat transfer past an exponentially porous stretching surface in presence of thermal radiation, Ain Shams Eng. J., 5, 205–21, 2014.

[3] M. Qasim, and S. Noreen, Heat transfer in boundary layer flow in a Casson fluid over permeable shrinking sheet with viscous dissipation, Euro. Phys. J. Plus., 129, 2014 14007–14015.

[4] M. Das, R. Mahato, and R. Nandkeolyar, Newtonian heating effect on unsteady hydromagnetic Casson fluid flow past a flat plate with heat and mass transfer, Alexandria +Engineering Journal, 54(4) ,871–87 9, 2015.

[5] Ullah, I., Khan, I., and Shafie, S.,: Hydromagnetic FalknerSkan flow of Casson fluid past a moving wedge with heat transfer, Alexandria Eng. J., 55, 2139-2148,2016.

[6] Mukhopadhyay, S., and Mandal, I. C.,: Boundary layer flow and heat transfer of a Casson fluid past a symmetric porous wedge with surface heat flux, Chinese Phys. B, 23, 44702,2004.

[7] Gilbert Makanda, Sachin Shaw and Precious Sibanda," Effects of radiation on MHD free convection of a Casson fluid from a horizontal circular cylinder with partial slip in non-Darcy porous medium with viscous dissipation", *Makanda et al. Boundary Value Problems*:**75** ,2015

[8] K. Sidda Reddy, P. Chandra Reddy, G.S.S. Raju, Thermal diffusion and Joule heating effects on MHD radiating fluid embedded in porous medium, International Journal for Research in Engineering Application & Management (IJREAM), 4(4), 206-212, 2018.

[9] S. Harinath Reddy, M.C. Raju, P. Chandra Reddy, Joule Heating and Radiation Absorption Effects on MHD Convective and Chemically Reactive Flow past a Porous Plate, Bulletin of Pure and Applied Sciences. 37E (1) 117-136, 2018.

[10] P. Loganathan and C. Sivapoornapriya , Ohmic Heating and Viscous Dissipation Effects over a vertical Plate in the presence of Porous Medium, Journal of Applied Fluid Mechanics, 9, 225-232, 2016.

[11] Goyal, M., Sunitha, Ch, MHD free convective flow over a vertical porous surface with Ohmic heating, thermal radiation and chemical reaction, International journal of science and Research, vol. 4(5), pp. 3206-3212, 2013.

[12] C.-H. Chen, Combined heat and mass transfer in MHD free convection from a vertical surface with Ohmic heating and viscous dissipation, International Journal of Engineering Science, Vol. 42, no. 7, pp. 699–713, 2004.

[13] M. Umamaheswar, S. V. K. Varma and M. C. Raju, "Unsteady MHD free convective visco-elastic fluid flow bounded by an infinite inclined porous plate in the presence of heat source, viscous dissipation and ohmic heating", International Journal of Advanced Science and Technology, 61, 39-52, 2013.

[14] L. Rama Mohan Reddy, M.C. Raju, P. Chandra Reddy, G.S.S. Raju, Thermal diffusion and Joule-heating effects on magnetohydrodynamic, free-convective, heat-absorbing/ generating, viscous-dissipative Newtonian fluid with variable temperature and concentration, International Journal of Fluid Mechanics Research, 45 (6) , 553–567,2018.

[15] R. Chandrasekhar Reddy , K. Jayarami Reddy, K. Ramakrishna ," Effects of Joule heating on MHD free convective flow along a moving vertical plate in porous medium", Special Topics & Reviews in Porous Media: An International Journal, vol. 10(1), **207-219,2016**.

[16] P. Chandra Reddy, M.C. Raju, G.S.S. Raju, Thermal and solutal buoyancy effect on MHD boundary layer flow of a visco-elastic fluid past a porous plate with varying suction and heat source in the presence of thermal diffusion, Journal of Applied & Computational Mathematics. 4(5),1-7,2015.

[17] P. Chandra Reddy, M.C. Raju, G.S.S. Raju, Magnetohydrodynamic convective double diffusive laminar boundary layer flow past an accelerated vertical plate, International Journal of Engineering Research in Africa. 20, 80-92, 2016.

[18] P. Chandra Reddy, M.C. Raju, G.S.S. Raju, Free convective heat and mass transfer flow of heat generating nano fluid past a vertical moving porous plate in conducting field, Special Topics and Reviews in Porous Media. 7(2), 161-180,2016.

[19] P. Chandra Reddy, M.C. Raju, G.S.S. Raju, C. Madhava Reddy, Diffusion thermo and thermal diffusion effects on MHD free convection flow of Rivlin-Ericksen fluid past a semi-infinite vertical plate, Bulletin of Pure and Applied Sciences. 36E(2) ,266-284,2017.

[20] N. Ananda Reddy, P. Chandra Reddy, M.C. Raju, S.V.K.Varma, Radiation and Dufour effects on laminar flow of a rotating fluid past a porous plate in conducting field, Frontiers in Heat and Mass Transfer, Int. Journal, 10 (4),1-7, 2018.

[21] D. Srinivasacharya,B. Mallikarjuna, R. Bhuvanavijaya," Soret and Dufour effects on mixed convection along a vertical wavy surface in a porous medium with variable properties", Ain Shams Engineering Journal ,6, 553–564, 2015.

[22] P. A. Lakshmi Narayana , P. V. S. N. Murthy, Soret and Dufour effects on free convection heat and Mass transfer from a horizontal flat plate in a Darcy porous medium, Journal of Heat Transfer, vol.130, 104504-1-104504-5, 2008.

[23] Rahman M.S, Samad M.A. "Dufour and Soret Effects on Unsteady MHD Free Convection and Mass Transfer Flow past a Vertical Porous Plate in a Porous Medium", Nonlinear Analysis: Modelling and Control, Vol. 11, No. 3, 217–226, 2006.

[24] Maleque .Kh. A.," Dufour and Soret effects on unsteady MHD Convective Heat and Mass

Transfer Flow due to a Rotating Disk", *Latin American Applied Research*,vol. **40**:105-111 2010.

[25] Mohyuddin, S. T., Ahmed, N., and Rashidi, M. M.,: A numerical study of thermo-diffusion, diffusion-thermo and chemical reaction effects on flow of a micropolar fluid in an asymmetric channel with dilating and contracting permeable wall., Eng. Comput., 34(2), 587-602,2017.

[26] T. Hayat, S. A. Shehzad." Soret and Dufour effects on magnetohydrodynamic (MHD) flow of Casson fluid ",*Appl. Math. Mech. -Engl*. Ed.,33(10),1301–1312,2012.