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Hall Current Effect on Chemically Reacting MHD Casson Fluid Flow with Dufour Effect and Thermal Radiation

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ABSTRACT

In this article it is examined Hall current effect on chemically reacting MHD Casson fluid flow with Dufour effects and thermal radiation. This problem is solved by using the perturbation technique for the velocity, the temperature and the concentration species. The skin friction, Nusselt number and Sherwood number are also obtained graphically. The effects of various physical parameters like as Chemical reaction parameter, Radiation parameter, Casson parameter, Schmidt number, Grashof number, Prandtl number, Dufour parameter and Hall current parameter has been discussed in detailed.

Keywords: MHD flow, Hall current, Casson fluid, Dufour effect, Chemical reaction.

2010 Mathematics Subject Classification: 74H10, 76W05, 80A20, 80A32.

1. INTRODUCTION

The influence of magnetic field on viscous, incompressible and electrically conducting fluid is of great importance in many applications such as magnetic material processing, glass manufacturing control processes and purification of crude oil. Hall current and chemical reaction effects on MHD flow is also significant in many cases. Vedavathi et al. [1] examined chemical reaction, radiation and Dufour effects on Casson MHD fluid flow over a vertical plate with heat source / sink. Squeezing flow of an electrically conducting Casson fluid has been taken into account. The laws of conservations under the similarity transformation suggested by Wang (1976) have been used to extract a highly nonlinear ordinary differential equation governing the Magneto hydrodynamic flow have been analyzed by Naveed Ahmed et al. [2]. Sandeep and Gnaneswara Reddy [3] developed the heat transfer nature of electrically conducting Magneto hydrodynamic Nano fluid flow over a cone and a wedge. The effects of surface dependent heat source / sink, viscosity and thermal conductivity variations on unsteady flow of Casson fluid over a vertical cone and flat plate with the influence of thermal radiation, temperature dependent heat source / sink and higher order chemical reaction effects presented by Mythili and Sivaraj [4]. Bala Anki Reddy [5] investigated the theoretical study of the steady two dimensional MHD convective boundary layer flow of a Casson fluid over an exponentially inclined permeable stretching surface in the presence of thermal radiation and chemical reaction. Naramgari Sandeep et al. [6] presented Three-dimensional Casson fluid flow towards a stagnation-point and a surface on which the heat energy falls at lower limit of thermodynamic temperature scale in the presence of cross diffusion and the governing equations are non-dimensionalized by using suitable similarity transformation, which unravels the behavior of the fluid flow at short-time and long-time period. Chalavadi Sulochana et al. [7] studied the Three-dimensional Magneto hydrodynamic Casson fluid flow, heat and mass transfer over a stretching surface in the presence of non-uniform heat source / sink, thermal radiation and Soret effect and the governing partial differential equations are transformed to nonlinear ordinary differential equations by using similarity transformation, which are then solved numerically using Runge-Kutta based shooting technique. Unsteady free convective hydro-Magnetic boundary layer Casson fluid flow past an oscillating vertical plate embedded through porous medium in the presence of uniform transverse Magnetic field, thermal radiation and chemical reaction is obtained by Hari R. Kataria and Harshad R. Patel [8]. Sulochana et al. [9] analyzed the three-dimensional Magneto hydrodynamic Newtonian and non-Newtonian fluid flow, heat and mass transfer over a stretching surface in the presence of thermophoresis and Brownian motion. The unsteady MHD free flow of a Casson fluid past an oscillating vertical plate with constant wall temperature, the fluid is electrically conducting and passing through a porous medium studied by Asam Khalid et al. [10].

Idowu et al. [11] presented the effect of chemical reaction on MHD oscillatory flow through a vertical porous plate with heat generation and the dimensionless governing equations for this model were solved by a closed analytical form. Ibrahim et al. [12] reported analytical solutions for heat and mass transfer by laminar flow of a Newtonian, viscous, electrically conducting and heat generation / absorbing fluid on a continuously vertical permeable surface in the presence of a radiation, a first-order homogeneous chemical reaction and the mass flux. The effects of chemical reaction, thermal radiation, Soret number, Dufour number and magnetic field on double-diffusion free convection flow along a sphere and the governing equations are solved numerically by an efficient, iterative, tri-diagonal, implicit finite difference method presented by Chamkha et al. [13]. Sreedevi et al. [14] analyzed the combined effects of the magnetic field, Joule heating, thermal radiation absorption, viscous dissipation, and buoyancy forces, thermal diffusion and diffusion-thermo on the convective heat and mass transfer flow of an electrically conducting fluid over a permeable vertically stretching sheet. Effects of Soret-Dufour, radiation and chemical reaction on an unsteady MHD flow of an incompressible viscous and electrically moving inclined plate and partial differential equations of non-dimensional form of governing equations of flow have been solved numerically using Crank-Nicolson implicit finite difference method is to investigated by Pandya et al. [15]. Harish Babu et al. [16] studied the combined effects of Soret and Dufour on Magneto hydrodynamics boundary layer flow of a Jeffrey fluid past a stretching surface with chemical reaction and heat source. Raptis [17] studied the effects of thermal radiation on the MHD flow over a vertical and porous plate of an optically thin gray electrically conducting viscous and incompressible fluid. Unsteady MHD natural convection flow of an optically thin, heat radiating, incompressible, viscous, chemically reactive, temperature dependent heat absorbing and electrically conducting fluid past an exponentially accelerated infinite vertical plate having ramped temperature, embedded in a porous medium is carried out, considering the effects of Hall current and rotation studied by Gauri Shanker Seth et al. [18]. Rajput and Gaurav Kumar [19] examined the effects of Hall current and chemical reaction on unsteady MHD flow through porous medium past an oscillating inclined plate with variable wall temperature and mass diffusion. The Magneto hydrodynamic and chemical reaction effects on unsteady flow, heat and mass transfer characteristic in a viscous, incompressible and electrically conduction fluid over a semi-infinite vertical porous plate in a slip-flow regime studied by Ahmed Sahin [20].

Dulal Pal and Babulal Talukdar [21] presented the problem of unsteady mixed convection with thermal radiation and first-order chemical reaction on Magneto hydrodynamic boundary layer flow of viscous, electrically conducting fluid past a vertical permeable plate. Vijayaragavan and Angeline Kavitha [22] investigated the Heat and Mass transfer characteristics of the MHD Casson fluid flow over a vertical plate in the presence of thermal radiation, chemical reaction and heat source / sink with buoyancy effects and the governing equations are solved using Perturbation technique. Emad M. Abo-Eldahab et al. [23] studied the effects of viscous dissipation and Joule heating on MHD free convection flow past a semi-infinite vertical flat plate in the presence of the combined effects of Hall and ion-slip current for the case of power-law variation of the wall temperature. Emad M. Aboeldahab et al. [24] presented Heat and Mass transfer along a vertical plate under the combined buoyancy force effects of thermal and species diffusion is investigated in the presence of a transversely applied uniform magnetic field and the Hall currents and the governing equations on the assumption of small magnetic Reynolds number are approximated by a system of non-linear ordinary differential equations solved by fourth-order Runge-Kutta method. Unsteady MHD Casson fluid flow through a parallel plate with Hall current and the uniform magnetic field is applied perpendicular to the plates and the fluid motion is subjected to a uniform suction and injection examined by Md Afikuzzaman et al. [25]. Sandeep et al. [26] analyzed the magnetic hydrodynamic, Radiation and Chemical reaction effects on unsteady flow, Heat and Mass transfer characteristic in a viscous, incompressible and electrically conducting fluid over a semi-infinite vertical porous plate through porous medium. The unsteady flow and heat transfer of a Casson fluid over a moving flat plate with a parallel free stream discussed by Mustafa et al. [27]. Magneto-hydrodynamic Casson fluid flow in two lateral directions past a porous linear stretching sheet is investigated by Nandeep et al. [28]. The effects of thermal radiation, chemical reaction and Soret number on Magneto-hydrodynamic heat and mass transfer of a Casson fluid in the presence of Magnetic field and viscous dissipation are analyzed by Dulal Pal and Sukanta Biswas [29]. Analytical solutions for heat and mass transfer by laminar flow of a Newtonian, viscous, electrically conducting and heat generation / absorbing fluid on a continuously vertical permeable surface in the presence of a radiation, a first-order homogeneous chemical reaction and the mass flux are reported by Ibrahim [30]. In this paper we are considering Hall current effect on chemically reacting MHD Casson flow with Dufour and thermal radiation. The results are shown with the help of graphs.

2. MATHEMATICAL ANALYSIS

MHD flow past an electrically non-conducting plate inclined at an angle from vertical is considered. The Geometrical model of the flow problem is shown in Fig.1.

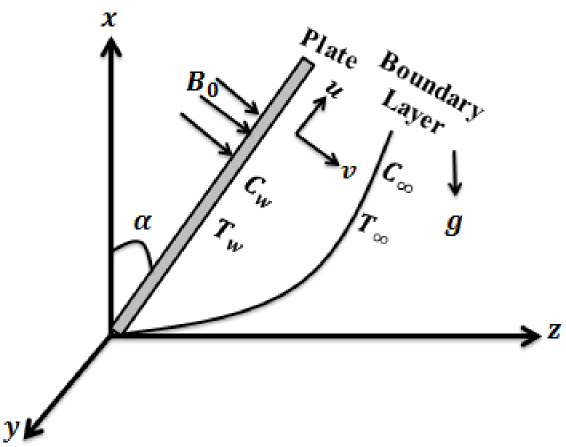

Fig.1. Physical Model

The x- axis is taken along the plane and z- normal to it. A transverse magnetic field B_0- uniform strength is applied on the flow. Initially, it has been considered that the plane as well as the fluid is at the same temperature-T_∞. The species concentration in the fluid taken as-C_∞. At time $t > 0$, the plate start oscillating in its own plane with frequency-ω, and temperature of the plate is raised to-T_w. The concentration-C near the plate is raised linearly with respect to time. Based on the above expectations the governing equations that describe the physical situation can be given in the Cartesian frame of reference as

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

$$\frac{\partial v}{\partial t} = \nu\left(1+\frac{1}{\beta}\right)\frac{\partial^2 v}{\partial z^2} + \frac{\sigma B_0^2\left(mu - v\right)}{\rho\left(1+m^2\right)} \tag{2}$$

$$\frac{\partial T}{\partial t} = \frac{k}{\rho C_p}\frac{\partial^2 T}{\partial z^2} - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial z} + \frac{D_m k_T}{C_s C_p}\frac{\partial^2 C}{\partial z^2} \tag{3}$$

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial z^2} - K_r\left(C - C_\infty\right) \tag{4}$$

The boundary conditions for the flow are as under:

$$\left.\begin{array}{l} t \le 0 : u = 0, v = 0, T = T_\infty, C = C_\infty, \\ t > 0 \begin{cases} u = u_0\cos\omega t, v = 0, T = T_\infty + \left(T_w - T_\infty\right)\dfrac{u_0^2 t}{\nu}, C = C_\infty + \left(C_w - C_\infty\right)\dfrac{u_0^2 t}{\nu} & at \;\; z = 0 \\ u \to 0, v \to 0, T \to T_\infty, C \to C_\infty & at \;\; z \to \infty \end{cases} \end{array}\right\} \tag{5}$$

Here u - the primary velocity, v - the secondary velocity, g - the acceleration due to gravity, β - volumetric coefficient of thermal expansion, t - time, $m\left(=\omega_e\tau_e\right)$ - the Hall current parameter with ω_e - cyclotron frequency of electrons and τ_e - electron collision of time, T - temperature of the fluid, β^* - volumetric coefficient, C - species concentration, ν - the kinematic viscosity, ρ - density, C_p - the specific heat, k - thermal conductivity of the fluid, D - the mass diffusion coefficient, K - permeability parameter, T_w - temperature of the plate at $z=0$, C_w - species concentration at the plate $z=0$, B_0 - the uniform magnetic field, Kr - chemical reaction, σ - electrical conductivity.

The local radiation gray gas is expressed by

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

Where a^* - absorption constant. The temperature difference within the flow is sufficiently small. Therefore, T^4 - can be expressed by expanding T_∞ and neglecting higher order terms.

$$T^4\cong 4T_\infty^3T-3T_\infty^4 \tag{7}$$

Using equations (6) and (7), from equation (3) becomes

$$\frac{\partial T}{\partial t}=\frac{k}{\rho C_p}\frac{\partial^2 T}{\partial z^2}-\frac{1}{\rho C_p}\left[16a^*\sigma T_\infty^3\left(T-T_\infty\right)\right]+\frac{D_m k_T}{C_s C_p}\frac{\partial^2 C}{\partial z^2} \tag{8}$$

The following non-dimension quantities are introduced to transform equations (1), (2), (4) and (8) into dimensionless form:

$$\left.\begin{array}{l} z^*=\frac{zu_0}{\nu},u^*=\frac{u}{u_0},v^*=\frac{v}{u_0},\theta=\frac{\left(T-T_\infty\right)}{\left(T_w-T_\infty\right)},Sc=\frac{\nu}{D},\mu=\rho\nu,\Pr=\frac{\mu C_p}{k},M=\frac{\sigma B_0^2\nu}{\rho u_0^2},\\ R=\frac{16a^*\sigma\nu^2T_\infty^3}{ku_0^2},\omega=\frac{\omega\nu}{u_0^2},Gm=\frac{g\beta^*\nu\left(C_w-C_\infty\right)}{u_0^3},C^*=\frac{\left(C-C_\infty\right)}{\left(C_w-C_\infty\right)},Gr=\frac{g\beta\nu\left(T_w-T_\infty\right)}{u_0^3},\\ t^*=\frac{tu_0^2}{\nu},K^*=\frac{Ku_0}{\nu^2},Kr^*=\frac{Kr\nu}{u_0^2},Du=\frac{D_mk_T\left(C_w-C_\infty\right)}{C_sC_p\nu\left(T_w-T_\infty\right)}, \end{array}\right\} \tag{9}$$

The symbols in dimensionless form are as under:

u^* - the primary velocity, v^* - the secondary velocity, t^* - time, θ - the temperature, C^* - the concentration, K^* - the permeability parameter, Gr - thermal Grashof number, Gm - mass Grashof number, Kr^* - chemical reaction parameter, μ - coefficient of viscosity, $\Pr$ - the Prandtl number, Sc - Schmidt number, R - radiation parameter, M - magnetic parameter, Du - Dufour effect.

The basic field equations (1), (2), (4) and (8) can be expressed in the non-dimensional form and dropping the stars $(*)$ as:

$$\frac{\partial u}{\partial t}=\left(1+\frac{1}{\beta}\right)\frac{\partial^2 u}{\partial z^2}+Gr\theta\cos\alpha+GmC\cos\alpha-\frac{M\left(u+mv\right)}{\left(1+m^2\right)} \quad (10)$$

$$\frac{\partial v}{\partial t}=\left(1+\frac{1}{\beta}\right)\frac{\partial^2 v}{\partial z^2}+\frac{M\left(mu-v\right)}{\left(1+m^2\right)} \quad (11)$$

$$\frac{\partial \theta}{\partial t}=\frac{1}{\Pr}\frac{\partial^2 T}{\partial z^2}-\frac{R}{\Pr}\theta+Du\frac{\partial^2 C}{\partial z^2} \quad (12)$$

$$\frac{\partial C}{\partial t}=\frac{1}{Sc}\frac{\partial^2 C}{\partial z^2}-KrC \quad (13)$$

The corresponding boundary conditions are:

$$\left.\begin{array}{l} t\le 0: u=0, v=0, \theta=0, C=0, \ for\ every\ \ z, \\ t>0: u=\cos\omega t, v=0, \theta=t, C=t \ \ at\ \ z=0 \\ u\to 0, v\to 0, \theta\to 0, C\to 0 \qquad as\ \ z\to\infty \end{array}\right\} \quad (14)$$

Combining equations (10) and (11), the model becomes

$$\frac{\partial U}{\partial t}=B\frac{\partial^2 U}{\partial z^2}+Gr\theta\cos\alpha+GmC\cos\alpha-\left[\frac{M\left(1-im\right)}{\left(1+m^2\right)}\right]U \quad (15)$$

Finally, the boundary condition becomes:

$$\left.\begin{array}{l} t\le 0: U=0, \theta=0, C=0, \ for\ every\ \ z, \\ t>0: U=\cos\omega t, \theta=t, C=t \ \ at\ \ z=0, \\ U\to 0,\ \theta\to 0, C\to 0 \qquad as\ \ z\to\infty, \end{array}\right\} \quad (16)$$

Here $B=\left(1+\frac{1}{\beta}\right)$ and $U=u+iv$

3. METHOD OF SOLUTION

Assuming the dimensionless quantities for velocity, temperature and concentration as:

$$U\left(z,t\right)=U_0\left(z\right)e^{i\omega t} \quad (17)$$

$$\theta\left(z,t\right)=\theta_0\left(z\right)e^{i\omega t} \quad (18)$$

$$C\left(z,t\right)=C_0\left(z\right)e^{i\omega t} \quad (19)$$

Substituting equations (17), (18) and (19) in equations (15), (12) and (13), we obtain:

$$BU_0''-\left(\frac{M\left(1-im\right)}{1+m^2}+i\omega\right)U_0=-Gr\theta_0\cos\alpha-GmC_0\cos\alpha \quad (20)$$

$$\theta_0'' - \left(R + i\omega \Pr\right)\theta_0 = -DuC_0'' \Pr \tag{21}$$

$$C_0'' - \left(i\omega + Kr\right)ScC_0 = 0 \tag{22}$$

Here the summits denote the differentiation with respect to z .

The respective boundary conditions are:

$$\left.\begin{array}{ll} U_0 = e^{-i\omega t}\cos(\omega t),\ \theta_0 = te^{-i\omega t},\ C_0 = te^{-i\omega t} & at\ z = 0, \\ U_0 \to 0,\quad \theta_0 \to 0,\ \ C_0 \to 0 & as\ z \to \infty, \end{array}\right\} \tag{23}$$

The analytical solutions of equations (20) - (22) with satisfying equations (23) are given by

$$U(z,t) = k_{10}e^{-k_5 z} + k_9 e^{-k_1 z} + k_6 e^{-k_2 z} \tag{24}$$

$$\theta(z,t) = (t - k_3)e^{-k_2 z} + k_3 e^{-k_1 z} \tag{25}$$

$$C(z,t) = te^{-k_1 z} \tag{26}$$

The expressions for the constants involved in the above equations are given in the appendix.

3.1 SKIN FRICTION

The dimensionless skin friction at the plate $z = 0$ is obtained by

$$C_f = \left(\frac{\partial U}{\partial z}\right)_{z=0} = -\left(k_5 k_{10} + k_1 k_9 + k_2 k_6\right) \tag{27}$$

3.2 NUSSELT NUMBER

The dimensionless Nusselt number at the plate $z = 0$ is obtained by

$$Nu = \left(\frac{\partial \theta}{\partial z}\right)_{z=0} = -\left(k_2\left(t - k_3\right) + k_1 k_3\right) \tag{28}$$

3.3 SHERWOOD NUMBER

$$Sh = \left(\frac{\partial C}{\partial z}\right)_{z=0} = -tk_1 \tag{29}$$

4. RESULTS AND DISCUSSION

This section effort to we have attained analytical explanations of velocity, temperature and concentration profiles for the study of hall current effect on chemically reacting MHD Casson fluid flow with Dufour effect and thermal radiation computed effects are presented in graphical system. The inspiration of different parameters like then $\Pr$ =7.0, Sc =0.60, Du =0.60, t =1.0, ω =1.0, Kr =0.50, R =0.50, β =0.50, M =1.0, m =0.20, Gr =1.0, Gm =5.0, $\alpha = \pi/6$ on the velocity, the temperature, the species concentration, the skin friction, Nusselt number and Sherwood number are obtained.

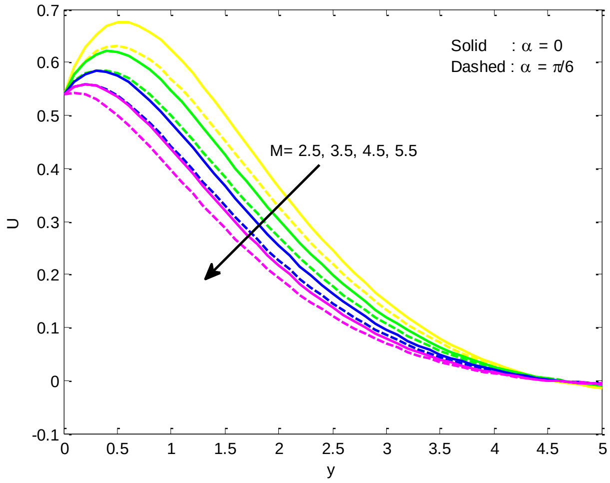

Fig.2. Velocity profile U for different values of M

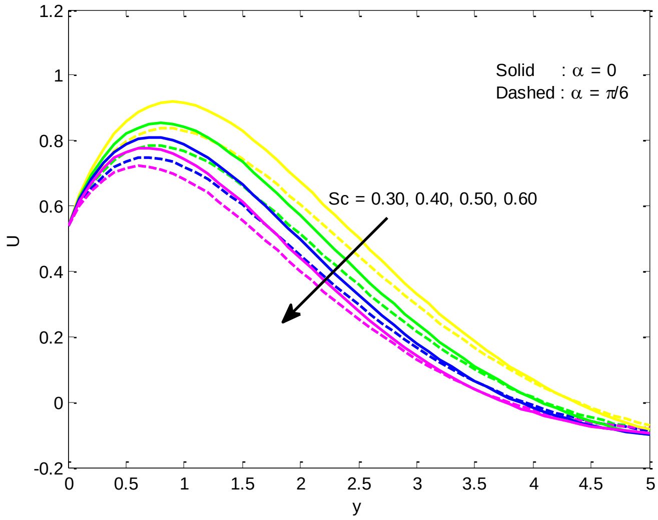

Fig.3. Velocity profile U for different values of Sc

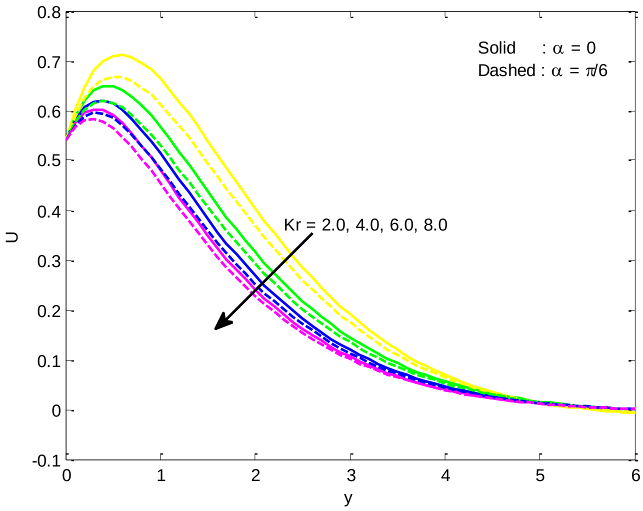

Fig.4. Velocity profile U for different values of Kr

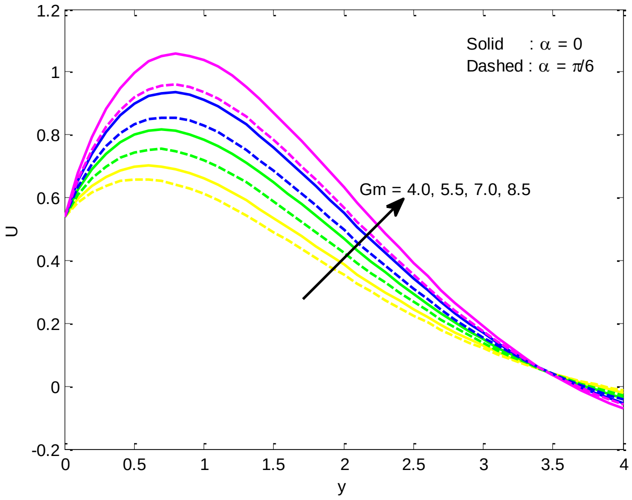

Fig.5. Velocity profile U for different values of Gm

Figs. 2 – 4. Shows that the velocities of fluid decreased with M , Sc and Kr are increases and **Fig.5.** Observed that the velocity increase with increasing the values of Gm .

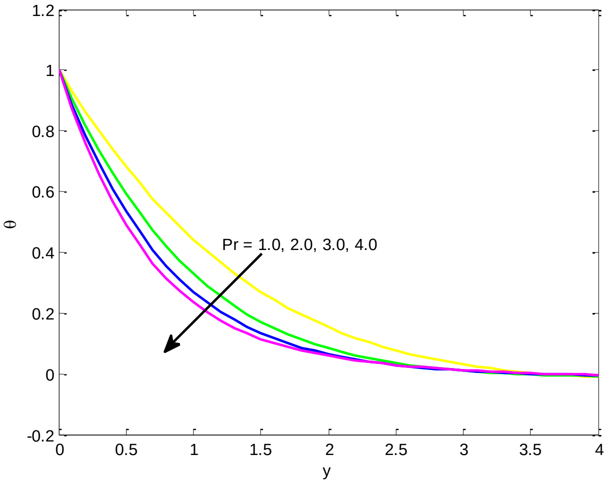

Fig.6. Temperature profile θ for different values of $\Pr$

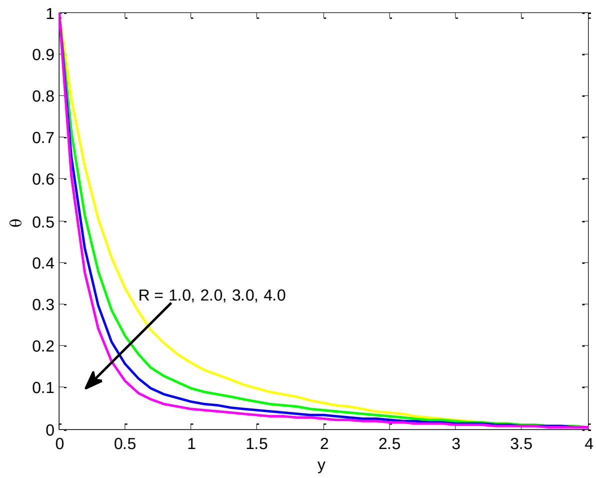

Fig.7. Temperature profile θ for different values of R

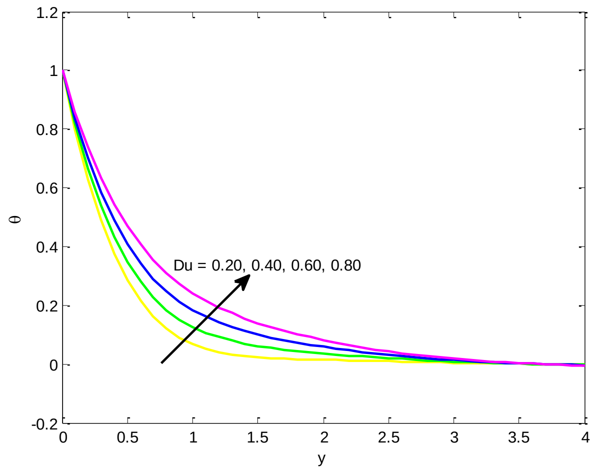

Fig.8. Temperature profile θ for different values of Du

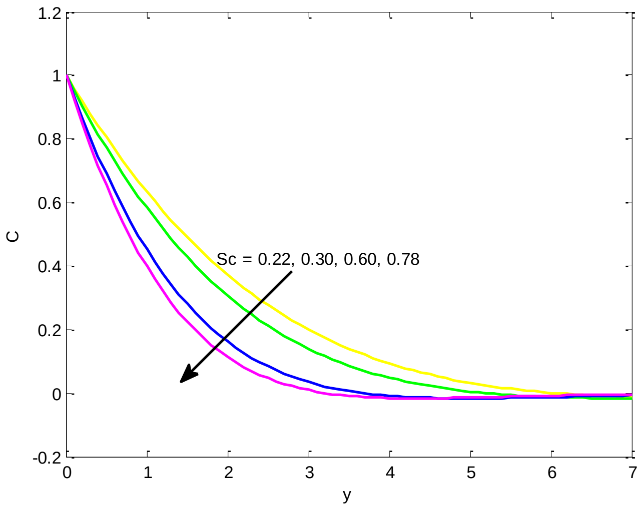

Fig.9. Concentration profile C for different values of Sc

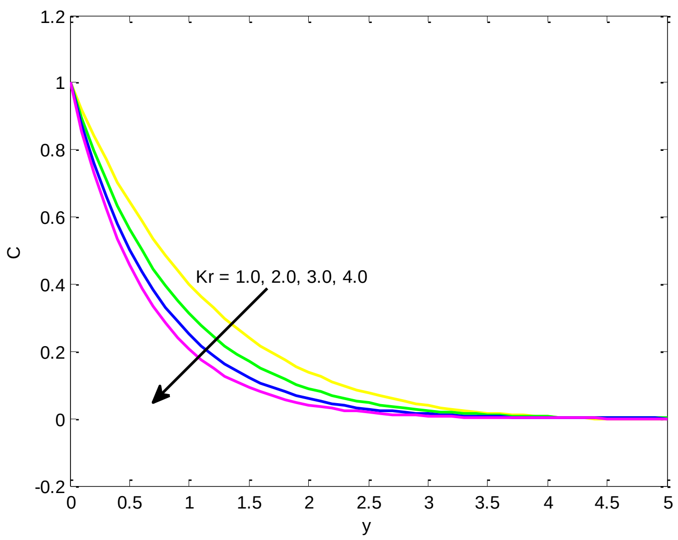

Fig.10. Concentration profile C for different values of Kr

From **Figs. 6 – 7.** Explained the characteristic of temperature profiles for various values of $\Pr$, R . We observed that the temperature will decreases with increasing values of the Prandtl number, Radiation parameter and **Fig. 8.** Illustrate the temperature will increase with the Dufour effect values of increasing.

Figs. 9 – 10. Displays that the concentration profiles for increasing values of Sc , Kr . We see that the concentration decreased with increasing the values of skin friction coefficient and chemical reaction parameter.

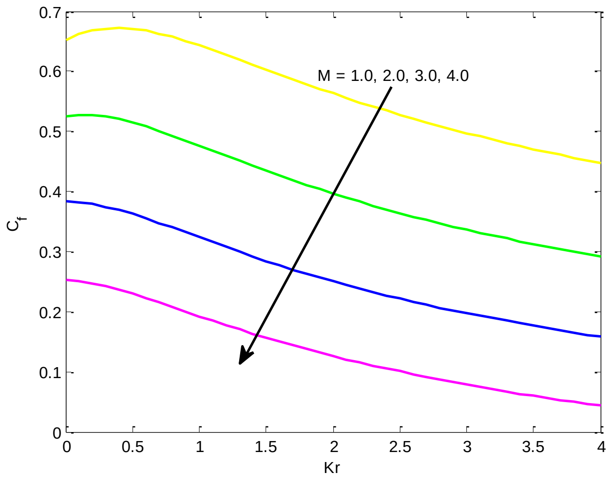

Fig.11. skin friction coefficient C_f for different values of M

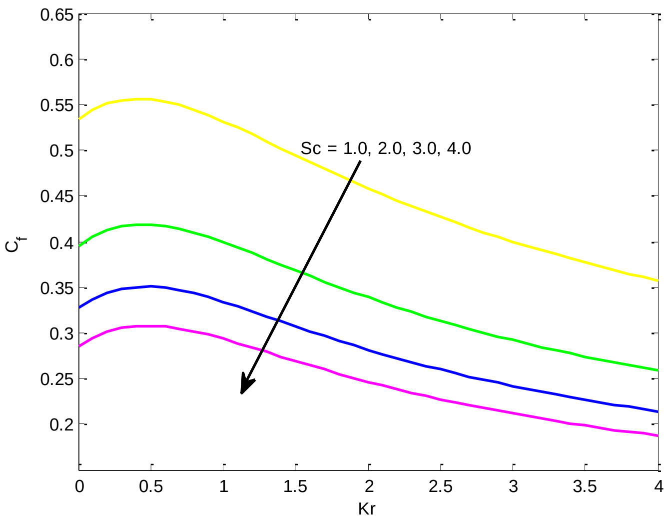

Fig.12. skin friction coefficient C_f for different values of Sc

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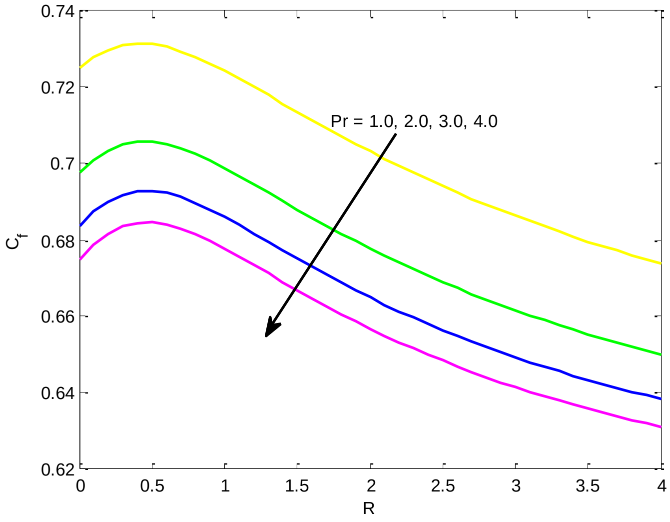

Fig.13. skin friction coefficient C_f for different values of Pr

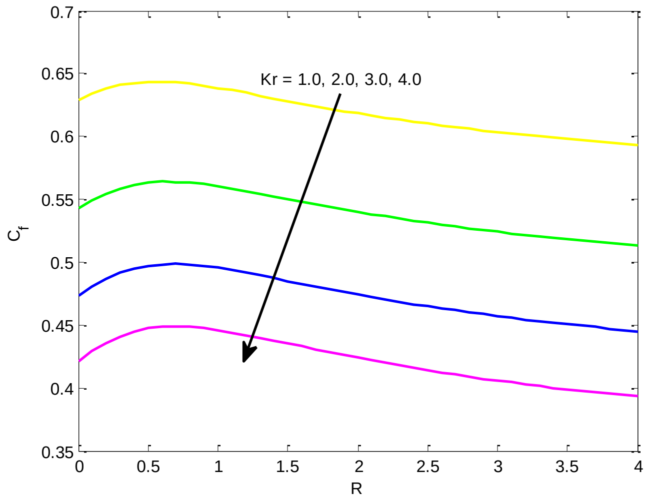

Fig.14. skin friction coefficient C_f for different values of Kr

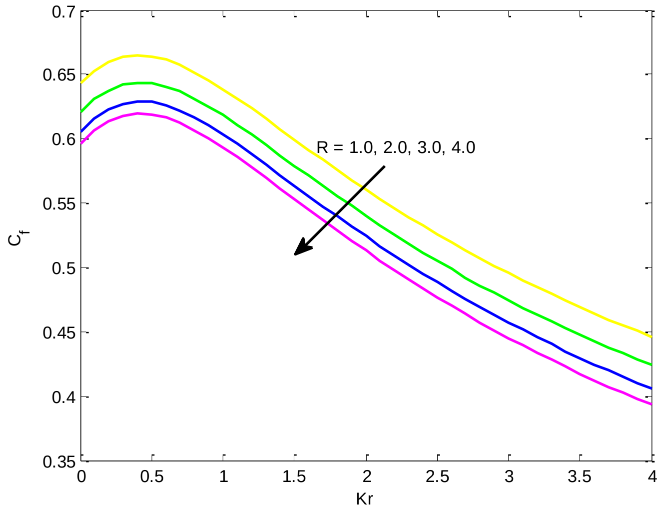

Fig.15. skin friction coefficient C_f for different values of R

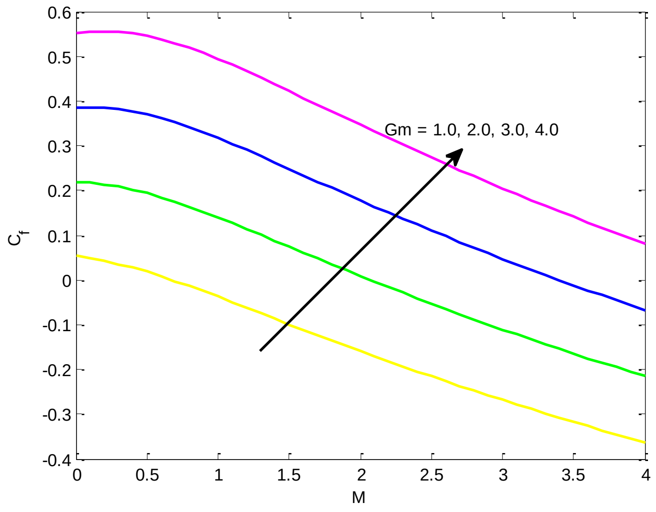

Fig.16. skin friction coefficient C_f for different values of Gm

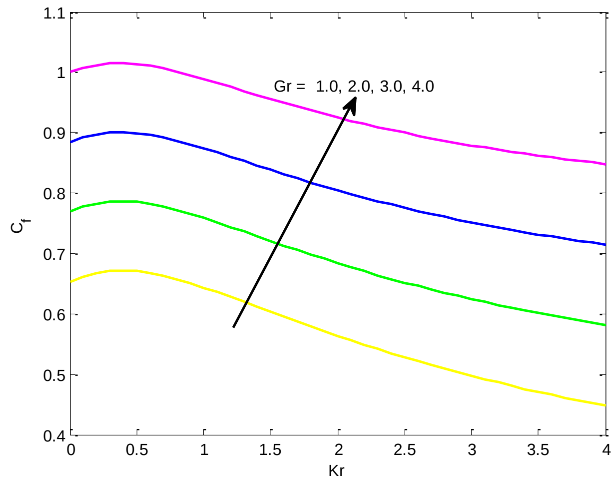

Fig.17. skin friction coefficient C_f for different values of Gr

From **Figs. 11 – 15.** Illustrates the behavior of the skin friction coefficient profiles are decreases with increasing the values of M , Sc , $\Pr$, Kr and R .

We conclude that increasing the values of magnetic parameter, Schmidt number, Prandtl number, chemical reaction parameter and radiation parameter with decreases the skin friction coefficient and **Figs. 16 – 17.** Signifies increasing the values of the Gm , Gr with increases the skin friction coefficient.

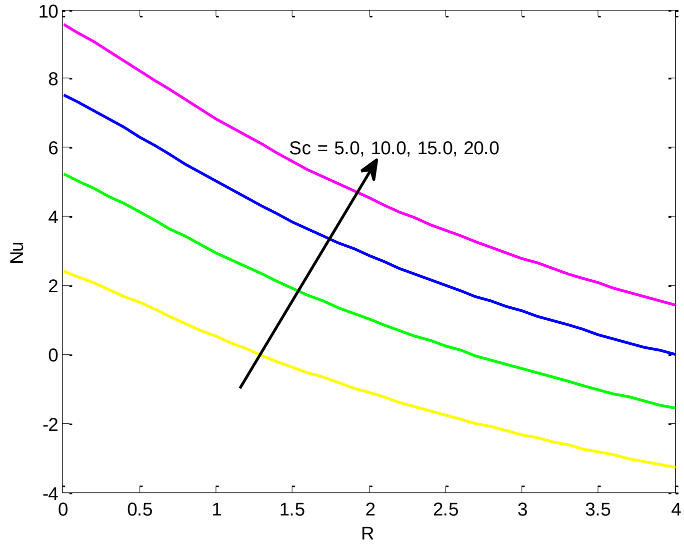

Fig.18. Nusselt number Nu for different values of Sc

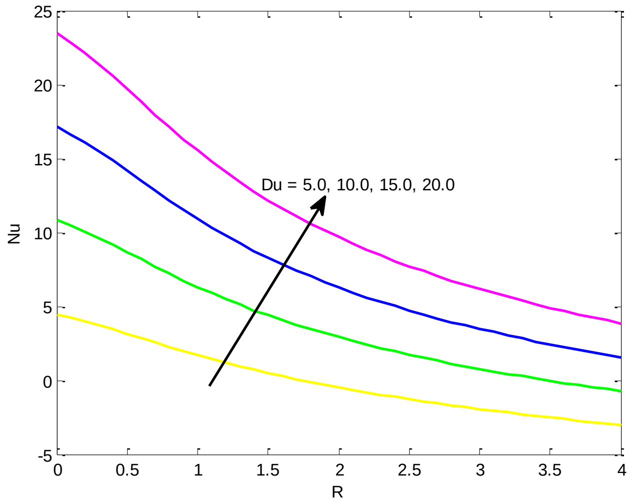

Fig.19. Nusselt number Nu for different values of Du

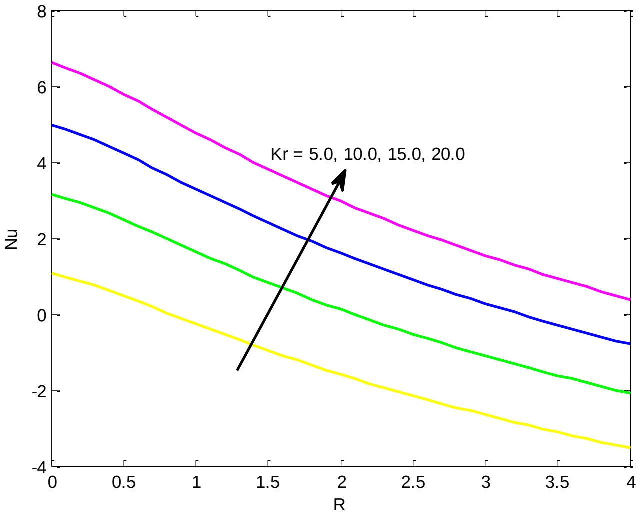

Fig.20. Nusselt number Nu for different values of Kr

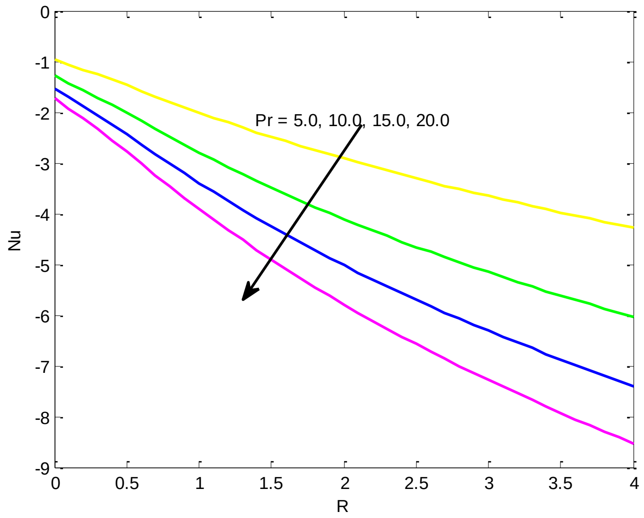

Fig.21. Nusselt number Nu for different values of $\Pr$

Figs. 18 – 20. Shows the characteristics of Nusselt number increases with increasing the values of Sc , Du , Kr . It is seen that the Nusselt number increases with increasing the values of Schmidt number, Dufour effect parameter and chemical reaction parameter and from **Fig. 21.** Shows that the Nusselt number decrease with increasing the values of Prandtl number.

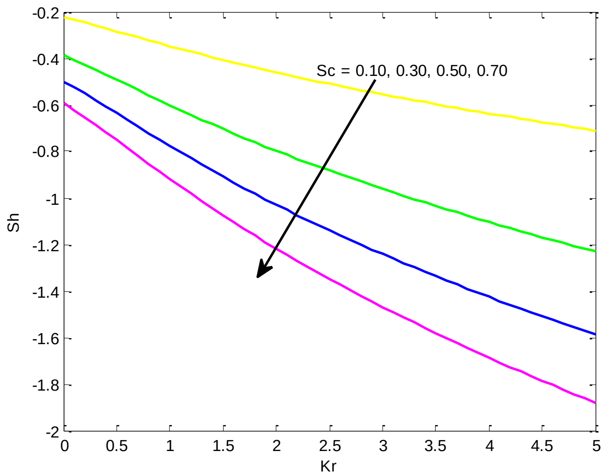

Fig.22. Sherwood number Sh for different values of Sc

Fig. 22. Displays that the Sherwood number decrease with increasing the values of Schmidt number.

5. CONCLUSION

In this article it is examined Hall current effect on chemically reacting MHD Casson fluid flow with Dufour effects and thermal radiation. This problem is solved by using the perturbation technique for the velocity, the temperature and the concentration species. The skin friction, Nusselt number and Sherwood number are also obtained graphically.

- The velocity in the boundary layer region increases when Magnetic parameter, Schmidt number and Chemical reaction parameter are increased.
- The temperature decreases with the increase in Prandtl number and Radiation parameter.
- The concentration decreases with the increase in skin-friction coefficient number and Chemical reaction parameter.
- The skin-friction coefficient decreases with the increase in Magnetic parameter, Schmidt number, Prandtl number, Chemical reaction parameter and Radiation parameter, and it increases with mass Grashof number and thermal Grashof number.
- Nusselt number increases with the increase in Schmidt number, Dufour parameter and Chemical reaction parameter, and it decrease with Prandtl number.
- Sherwood number decreases with increase in Schmidt number.

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APPENDIX

$$k_1 = \sqrt{(Kr + i\omega)Sc},\ k_2 = \sqrt{R + i\omega \Pr},\ k_3 = \frac{-Du \Pr k_1^2 t}{k_1^2 - k_2^2},\ k_4 = \frac{M(1 - im)}{1 + m^2},\ k_5 = \sqrt{\frac{k_4 + i\omega}{B}},$$

$$k_6 = \frac{-Gr\cos\alpha(t - k_3)}{B(k_2^2 - k_5^5)},\ k_7 = \frac{-Gr\cos\alpha k_3}{B(k_1^2 - k_5^5)},\ k_8 = \frac{-Gm\cos\alpha t}{B(k_1^2 - k_5^5)},\ k_9 = k_7 + k_8,\ k_{10} = \cos\omega t - k_6 - k_9$$