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MHD Flow Of A Second-order Fluid Past A Tilted Oscillating Plate Embedded In A Porous Medium Considering Magnetic Dissipation

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--*ABSTRACT*--

The problem of diffusion of thermal energy and of chemical species in presence of homogeneous chemical reaction of first order of free convection flow of electrically conducting viscoelastic second order Rivlin-Erickson fluid which is an optically thin gray gas past an oscillating tilted plate in porous medium is investigated. The heat due to viscous and magnetic dissipation is taken into consideration under temperature gradient heat sources in the case of variable plate temperature and mass diffusion. Non-linear partial differential equations emerged from the modeling have being made dimensionless, using suitable non-dimensional variables; and then solved by employing the symbolic computational software MAPLE. The resulting numerical solutions concerned with velocity, temperature and concentration for different values of the governing parameters are illustrated graphically and discussed quantitatively.

KEYWORDS: *Magnetic dissipation, Second order fluid, Theta method scheme, Tilted oscillating plate, viscous dissipation.*

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I. INTRODUCTION

Time-varying natural convection by buoyancy mechanisms arising from both thermal and species diffusion past an infinite vertical oscillating plate, in the presence of homogeneous chemical reaction of first order has been studied. The interest in this type of flow problems is owing to its universal occurrence in branches of science and engineering. For instance in power industry, chemical process industries, cooling of nuclear reactions, hydromagnetic power generators, geothermal energy extractions processes, petroleum engineering, and so on. Muthucumaraswamy and Meenakshisundaram [1] worked on this flow problem considering variable plate temperature and mass diffusion. Muthucumaraswamy and Janakiraman [2] examined a case of constant plate temperature and mass diffusion. MHD flow is significant in many cases, due to its diverse applications. Combined heat and mass transfer from different geometries embedded in a porous medim has applications in geophysics and engineering such has enhanced oil recovery, underground energy transport, geothermal reservoirs, and nuclear reactors. Transient free convection plays an important role in many industrial and environmental situations. Viscous dissipation occur in free convection in various devices which operate at high rotative speeds or which are subject to large deceleration. Radiation in absorbing and emitting media in free convection heat transfer is also important in many industrial and in engineering applications. Accordingly, Kishore et al. [3] numerically looked at the work of [1] under the influence of transversely applied uniform magnetic field in the presence of radiation, viscous dissipation and porous medium; excluding chemical reaction. Aligned magnetic field and heat source/sink impact was also studied by Sandeep and Sugunamma [4]. A Soret and Dufour effect on MHD flow in the presence of temperature dependent heat source/sink is significant and has been examined by Fasogbon and Tijani [5]. However, this flow problems adjacent to tilted plate have received the attention of many researchers. Dhote and Thombre [6], from their review article, came into a conclusion, among other things, that the type of cited above geometry is insufficient and there is need to devise more accurate to understand the flow characters if the vertical oscillating plate is tilted because of its practical applications in heat transfer technology like solar collector, and in the present work we join the train to demonstrate the issue. Problems with tilted geometry are more of practical situations. Alam et al. [7] investigated the Hall current and magnetic field effects on heat and mass transfer characteristics of hydromagnetic free convection of steady flow over an inclined plate. Rajput and Kumar [8], Rajput and Kumar [9] and Hari et al. [10] studied, Soret and permeability parameter effects, chemical reaction and Hall current effects, and radiation and chemical reaction effects, respectfully, on unsteady MHD flow past an oscillating inclined plate with variable temperature and mass diffusion.

Nomenclature

T	Cauchy stress tensor	(x, y)	dimensionless coordinate system
(X, Y)	dimensional coordinate	$\vec{B}$	magnetic induction vector
I	unit matrix (tensor)	(u, v)	dimensionless velocity components
(u', v')	Dimensional velocity components in (x' , y') direction	p'	fluid pressure
k_p	Permeability parameter	p_r	Prandtl number
B_0	Uniform applied magnetic field	q_r	radiative heat flux
C_p	Specific heat at constant pressure	N	radiation parameter
ωt	phase angle	S	heat source/sink parameter
E_c	Eckert number	G_m	mass Grashof number
D_m	Mass diffusion coefficient	C'	species concentration in the fluid
$\underset{\rightarrow}{g}$	Acceleration due to gravity		Greek symbols
t'	Dimensional time variable	δ_c	chemical reaction parameter
t	Time	α	tilt angle
M	magnetic field parameter	α^1, α^2	material moduli
S_c	Schmidt number	A^1, A^2	Rivlin-Erickson tensors
G_r	Thermal Grashof number	β	viscoelastic parameter
P	pressure	β_m	coefficient of mass expansion
T	fluid temperature	β_T	coefficient of thermal expansion
T_∞	ambient temperature	σ_e	electrical conductivity
T_w	Temperature of the plate	ρ_e	space charge transport
J_e	magnetic dissipation	ρ	fluid density
K	Thermal conductivity	μ	dynamic viscosity
k'	Permeability of the porous medium	ν	kinematic viscosity
$\vec{J}$	Electric current density	ϕ	viscous dissipation term
k_m	Mean absorption coefficient	σ_s	Stefan-Boltzmann

Another interesting problem is the combined action of viscous and magnetic dissipations to explore the impact of the magnetic field on the thermal transport where the fluid medium is assumed to possess a significantly high electrical conductivity at high-speed flow. Other vital application is in various devices which are subjected to large variations of gravitational force. In view of these applications, Jaber [11] and Jaber [12] considered the effects of viscous dissipation and Joule heating on MHD flow,of fluid with variable properties past a stretching vertical plate, and over a stretching porous sheet subjected to power law heat flux in presence of heat, respectfully. Recently, effect of viscous dissipation on power law-fluid past a permeable stretching sheet in a porous media was considered by Devi et al. [13].

In all the aforementioned manuscripts, attempts have been confined to Newtonian fluid. However, in processing industries such as polymer industry, petroleum industries, and many more where materials like molten plastics, polymer solutions or melts, drilling mud, certain oils and greases, slurries and many other emulsions, whose flow behavior do not obey the assumption of Newtonian fluids, that the stress tensor is directly proportional to the deformation tensor are found and classified as non-Newtonian (i.e. predominant industrial materials, such as in food, polymer, petrochemical, rubber and paint) fluid, hence the study of such fluids is desirable. non-Newtonian fluid flows' applications are seen in the polymer sheet, extrusion from a dye, glass fiber and paper production, drilling of oil and gas wells, drawing of plastic films, waste fluids, to mention but few. Owing to complexity of fluids, a variety of models have been suggested to describe the flow, heat and mass transfer of non-Newtonian characteristics. Constitutive equations are the models, and cannot describe all the behaviors of these non-Newtonian fluids because of differences in normal stress, shearing thinning or shearing thickening, stress relaxation, elastic and memory effects, and so on. The second grade fluid is of differential type, describe normal stress difference. The flow problems where second grade fluid is predominant, the third order partial differential equations are noticed unlike the second order partial differential equations obtainable in viscous fluid. The usual practice required an additional boundary condition to solve the resulting equations. But, due to geometric configuration and flow conditions under consideration as in the present work, this is not necessary. Thus, owing to simplicity, fluids of second grade have gained much attention from scholars. Some exact solutions for unsteady unidirectional MHD flows of a class of non-Newtonian fluid saturated in a porous medium was obtained (see Liu [14] and the literature cited therein). The effects of thermal buoyancy on flow of a viscoelastic second grade fluid past a vertical continuous stretching sheet with variable surface temperature was explained by Mushtag et al. [15]. Kavitha et al. [16] examined at length, the Darcy's effect on convective MHD flow of a second order fluid in an inclined porous channel. Kothandapani [17] employed Homotopy Analysis Method to obtain solution of the influence of exponential viscosity on an electrically conducting second-order fluid for the developed flow past a stretching sheet. An analysis on oscillatory MHD convection slip flow of a viscoelastic fluid through the porous medium bounded by two infinite vertical porous plates was presented by Singh [18]. Kham and Zaman [19] presented analytical solutions for unsteady magnetohydrodynamic flows of second grade fluid due to impulsive motion of plate. Most recently, an investigation of the heat and mass transfer on the flow of an oscillatory convective MHD viscous incompressible, radiating and electrically conducting second grade fluid in a vertical porous rotating channel in slip flow regime is carried out by Reddy and Reddy [20].

In this manuscript; motivated by the above studies, we examine the combined impacts of viscous and magnetic dissipations on radiating electrically conducting viscoelastic second grade fluid past an infinitely long tilted oscillating plate embedded in a porous medium under the homogeneous chemical reaction of first-order in presence of temperature gradient heat sources in case of variable temperature and mass diffusion using the symbolic software MAPLE (Theta Method Scheme) to solve the resulting dimensionless nonlinear partial differential equations. The results for velocity, temperature and concentration profiles are examined for various values of key parameters.

II. MATHEMATICAL FORMULATION

We consider the transient two-dimensional laminar incompressible electrically conducting viscoelastic second grade fluid past an infinite oscillating plate with an acute angle α. x' -axis is taken along the leading edge of tilted plate and y' -axis is normal to it. The fluid is considered to be gray, absorbing-emitting, but non-scattering medium and the Rosseland approximation is used to describe the radiative heat flux in the energy equation. The radiative heat flux in the x' -direction is ignored to the flux in the y' -direction, i.e. $q_r = \frac{4\sigma_s}{3k_m}\frac{\partial T^4}{\partial y'}$. Applied electric field is absent and the magnetic Reynold's number is small enough so that the induced magnetic field is neglected and a magnetic field of strength B_0 applied in y' -axis direction and give rise to magnetic force $\vec{F}_e$. The equations governing the MHD free convection flow of incompressible second grade viscoelastic fluid are:

The continuity equation:

$$\nabla \cdot \vec{u} = 0 \tag{1}$$

The momentum equation:

$$\rho \frac{d\vec{u}}{dt'} = \nabla \cdot T + \vec{F}_e + \rho \underset{\rightarrow}{g} - \frac{\mu}{k'}\vec{u} \tag{2}$$

The energy equation:

$$\rho C_p \frac{dT}{dt'} = K\nabla^2 T + \phi + \frac{\vec{J}^2}{\sigma_e} - \frac{\partial q_r}{\partial y'} + Q\frac{\partial T}{\partial y'} \tag{3}$$

The species concentration equation:

$$\frac{dC'}{dt'} = D_m \nabla^2 C - k_r (C' - C'_\infty) \tag{4}$$

The constitutive equation of second-order incompressible viscoelastic fluid flow defined by Rivlin-Erickson is:

$$T = -p'I + \mu A^1 + \alpha^1 A^2 + \alpha^2 A^1, \qquad (5)$$

where

$$A^1 = \nabla\vec{u} + (\nabla\vec{u})^\tau, \; A^2 = \frac{d}{dt'} A^1 + A^1 \nabla\vec{u} + (\nabla\vec{u})^\tau A^1,$$

$\frac{d}{dt'}$ denotes the material time derivatives and $\vec{u}$ = (u, v, 0) denotes the velocity. (5) is considered to be an exact model for some non-Newtonion fluids; compatible with thermodynamics in the sense that the Clausius-Duhem inequality be met in all motion and that the Helmholtz free energy be a minimum when the fluid is at rest, hence, conditions: $\mu \geq 0$, $\alpha^1 \geq 0$, and $\alpha^1 + \alpha^2 = 0$ must hold for material moduli.

$\vec{F}_e = \vec{J}\Lambda\vec{B} = \sigma_e(\vec{u}\Lambda\vec{B})\Lambda\vec{B} = -\sigma_e B_0^2 u$ in x' -direction, satisfying the Maxwell's equations: $\nabla \cdot B = 0$ (Gauss's law of magnetism), $\nabla \times \vec{B} = \vec{J}, \nabla \cdot \vec{E} = 0$ and $\vec{J} = \sigma_e \vec{u} \times \vec{B}$ (Ohm's law). Also omitted are Maxwell currents displacement and free charges. Initially the plate and the fluid are of the same temperature T with species concentration C'. At time t' > 0, the plate starts oscillating in its own plane with a velocity $u_0 \cos\omega' t'$, frequency ω', the plate temperature is raised to T_w and the concentration level at the plate is raised to $C_w^{'}$. The temperature and concentration near the plate is raised linearly with respect to time. Properties of the fluid are assumed constant except that density change with temperature that brings about the buoyancy forces in a manner corresponding to the equation of state $\rho_\infty = \rho[1+\beta_T(T-T_\infty)+\beta_m(C'-C_\infty^{'})]$. Since the plate is infinite in extent, all physical quantities, except pressure, are functions of y' and t'. By virtue of the above assumptions, the resulting governing equations from (1)-(4) are:

$$\rho\frac{\partial u'}{\partial t'} = \mu\frac{\partial^2 u'}{\partial y'^2} + g\beta_T(T-T_\infty)\cos\alpha + g\beta_m(C'-C_\infty^{'}) - \frac{\mu}{k'}u' - \sigma_e B_0^2 u' + \alpha^1\frac{\partial^3 u'}{\partial t'\partial y'^2} \qquad (6)$$

$$\rho C_p\frac{\partial T}{\partial t'} = K\frac{\partial^2 T}{\partial y'^2} + \mu(\frac{\partial u'}{\partial y'})^2 + \sigma_e B_0^2 u'^2 + Q\frac{\partial T}{\partial y'} - \frac{\partial q_r}{\partial y'} \qquad (7)$$

$$\frac{\partial C'}{\partial t'} = D_m\frac{\partial^2 C'}{\partial y'^2} - k_r(C'-C_\infty^{'}) \qquad (8)$$

with the following and initial boundary conditions:

$$t' \leq 0: u' = 0, T = T_\infty, C' = C_\infty^{'}, \forall y'$$

$$t' > 0: \; u' = u_0\cos\omega' t', \; T = T_\infty + (T_w - T_\infty)\frac{u_0^2}{\upsilon}t', \; C' = C_\infty^{'} + (C_w^{'} - C_\infty^{'})\frac{u_0^2}{\upsilon}t' \text{ at } y' = 0 \qquad (9)$$

$$u' \to 0, T \to T_\infty, C' \to C_\infty, \text{ as } y' \to \infty$$

In dimensionless form, we have:

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} + G_r\theta\cos\alpha + G_m C\cos\alpha + \beta\frac{\partial^3 u}{\partial t\partial y^2} - Mu - \frac{1}{k_p}u \qquad (10)$$

$$P_r\frac{\partial\theta}{\partial t} = \left(1+\frac{4}{3N}\right)\frac{\partial^2\theta}{\partial y^2} + P_r E_c\left(\frac{\partial u}{\partial y}\right)^2 + S\frac{\partial\theta}{\partial y} + J_e E_c u^2 \qquad (11)$$

$$S_c\frac{\partial C}{\partial t} = \frac{\partial^2 C}{\partial y^2} - S_c\delta_c C \qquad (12)$$

satisfying

$$t \leq 0: u = 0, \theta = 0, C = 0 \;\forall\; y$$

$$t > 0: u = \cos\omega t, \theta = t, C = t \text{ at } y = 0 \qquad (13)$$

$$u = 0, \theta \to 0, C \to 0 \text{ as } y \to \infty$$

using dimensionless variables:

$$u=\frac{u'}{u_0},t=\frac{t'u_0^2}{\upsilon},y=\frac{y'u_0}{\upsilon},x=\frac{x'u_0}{\upsilon},\delta_c=\frac{k_r\upsilon}{u_0^2},P_r=\frac{\mu C_p}{K},\beta=\frac{\alpha^1u_0^2}{\rho\upsilon^2},G_r=\frac{g\beta_T\upsilon(T_w-T_\infty)}{u_0^2}$$

$$\theta=\frac{T-T_\infty}{T_w-T_\infty},C=\frac{C'-C_\infty^{'}}{C_w^{'}-C_\infty^{'}},\omega=\frac{\omega'\upsilon}{u_0^2},p=\frac{p'}{\rho u_0^2},S=\frac{Q\upsilon}{Ku_0},J_e=\frac{\sigma_eB_0^2\upsilon^2C_p}{Ku_0^2}$$

$$E_c=\frac{u_0^2}{C_p(T_w-T_\infty)},M=\frac{\upsilon\sigma_eB_0^2}{\rho u_0^2},N=\frac{k_mK}{4\sigma_sT_\infty^3},k_p=\frac{k'u_0^2}{\upsilon^2},S_c=\frac{\upsilon}{D_m},G_m=\frac{g\beta_m\upsilon(C_w^{'}-C_\infty^{'})}{u_0^2}$$

III. RESULTS AND DISCUSSIONS

The system of nonlinear partial differential equations (10) – (12) with the boundary condition (13) have been solved in the symbolic algebra software MAPLE using Theta method scheme. For numerical computation, the far away condition has been taken at a large but finite value of y where there is no considerable variation in velocity, temperature and chemical species concentration. The computations have been performed for different values of angle of inclination parameter α, heat source/sink parameter S, viscous dissipation parameter (Eckert number) E_c, magnetic dissipation parameter (Joule heating) J_e, chemical reaction parameter δ_c, and second grade fluid parameter β, shown graphically in Fig.1 – Fig.16. The default parameters used throughout the numerical computations are: α = π/4, β = 1.0, δ_c = 2.0, E_c = 1.0, J_c = 1.5 and S = 1.0. Some physically meaningful values for the parameters chosen are: the Prandtl number P_r (= 0.71) corresponds to the air at 20⁰C and one atmospheric pressure, the Schmidt number chosen to represent the presence of species; Helium (S_c = 0.30, diffusing in electrically conducting air), S from -1.0 (heat sink) through 0.0 (absent of source) to 2.0 (heat source) and the chemical reaction parameter δ_c takes value ±2, ±4, ±5 (endothermic δ_c>0, exothermic δ_c<0). The positive values chosen for Eckert number corresponds to plate cooling, which implies loss of heat from the plate to the fluid.

Fig.1 and Fig.2 represent the effect of angle of inclination α on velocity u and temperature θ, respectively, fixed values of other parameters. One can observe that increase in tilt angle α has the tendency to decrease the velocity and temperature of the fluid, significantly.

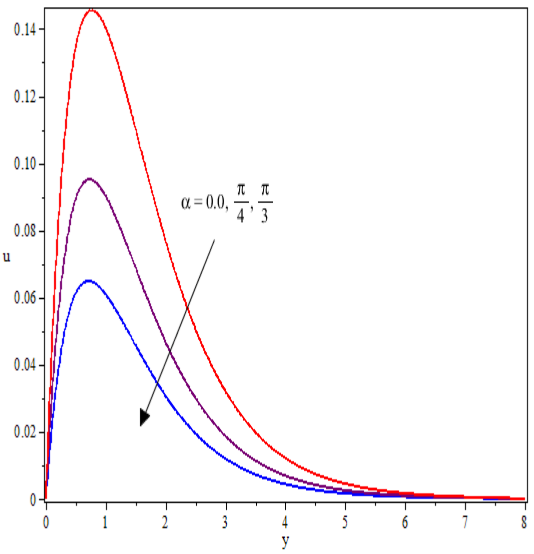

Fig. 1: u vs. y for α

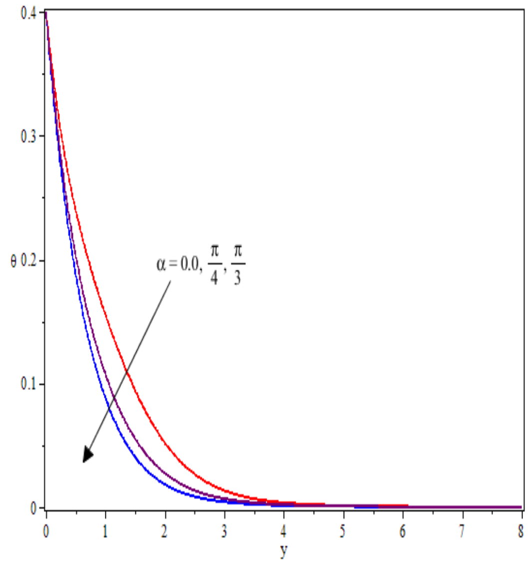

Fig. 2: θ vs. y for α

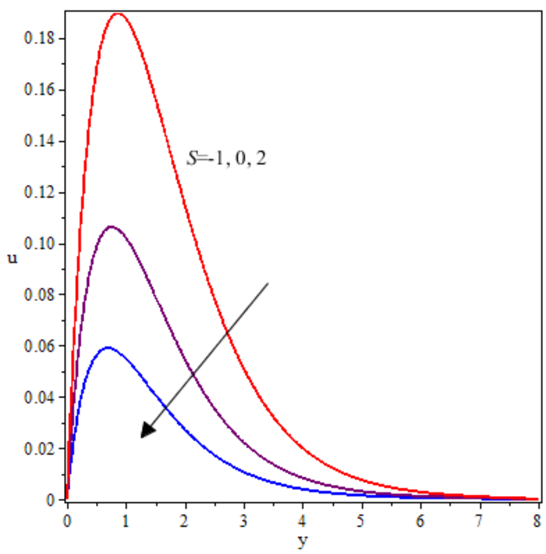

Fig. 3: u vs. y for S

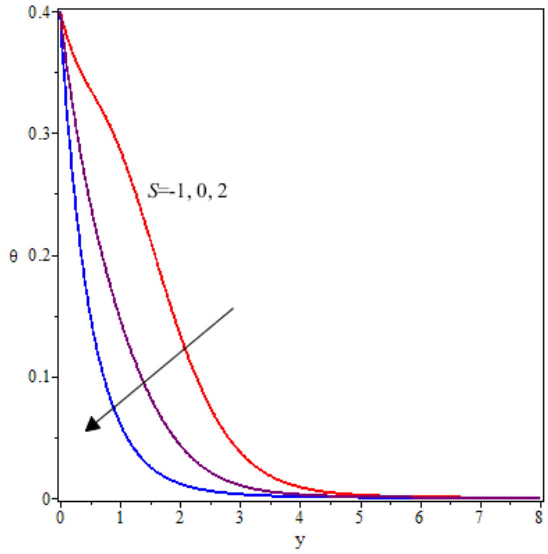

Fig. 4: θ vs. y for S

The graph for velocity and the temperature of the fluid for different values of heat source/sink parameter S is plotted in Fig.3 and Fig.4, respectively. The analyses of graphs reveal that the effect of an increase in S is to considerably reduce velocity and temperature of the fluid.

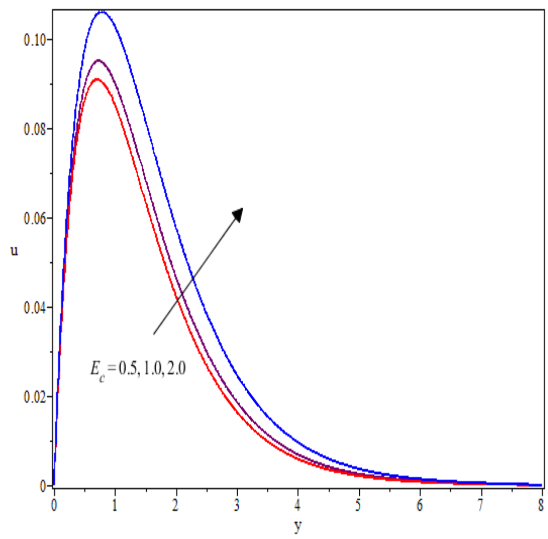

Fig. 5: u vs. y for E_c

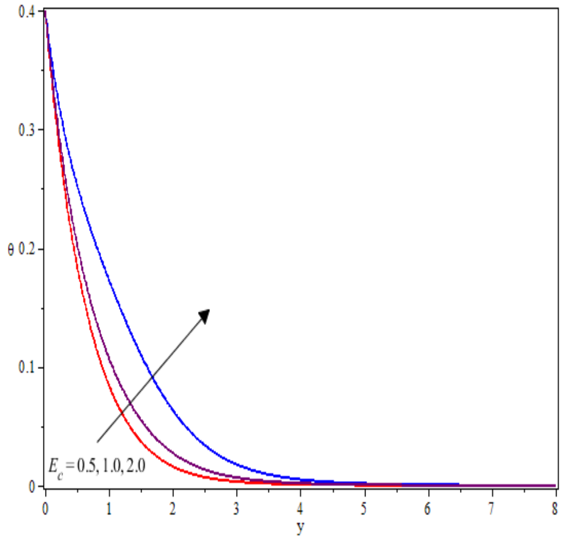

Fig. 6: θ vs. y for E_c

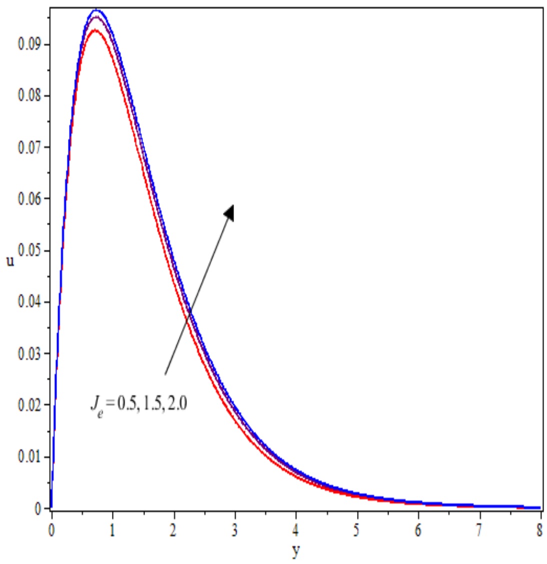

Fig. 7: u vs. y for J_c

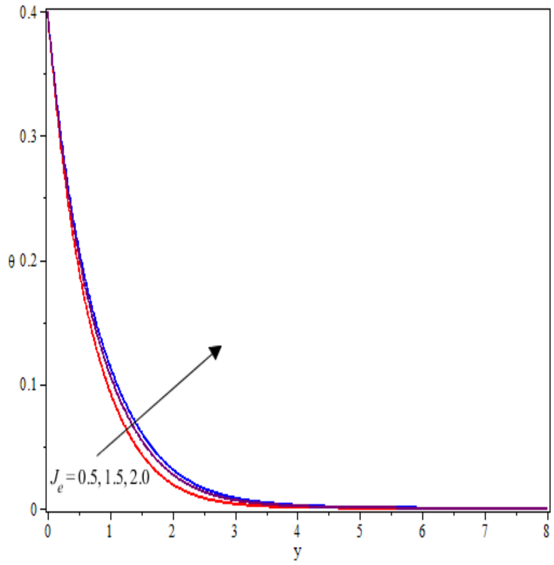

Fig.8: θ vs. y for J_c

Enhancement of the Eckert number significantly increases velocity (Fig.5) and temperature (Fig.6) of the fluid. Effect of Joule heating J_c on velocity and temperature is depicted in Fig.7 and Fig.8, respectively. As it shown in the figures, increase in Joule heating parameter causes increase in each of the quantities. It is clear that viscous dissipation has stronger influence on fluid motion and temperature over magnetic dissipation.

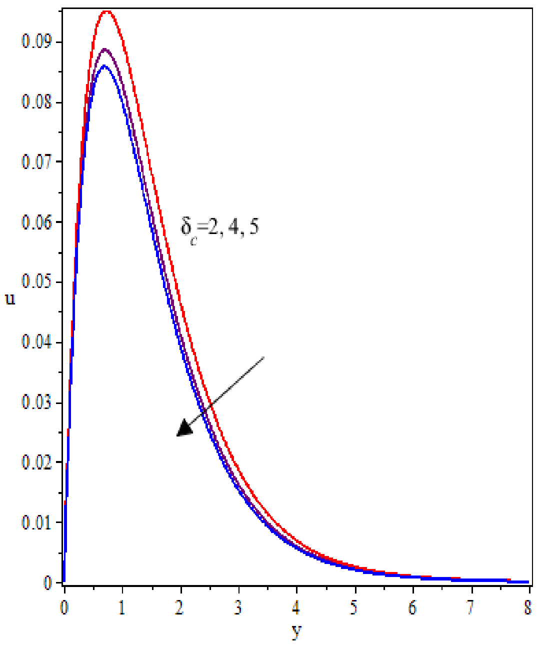

Fig. 9: u vs. y for δ_c

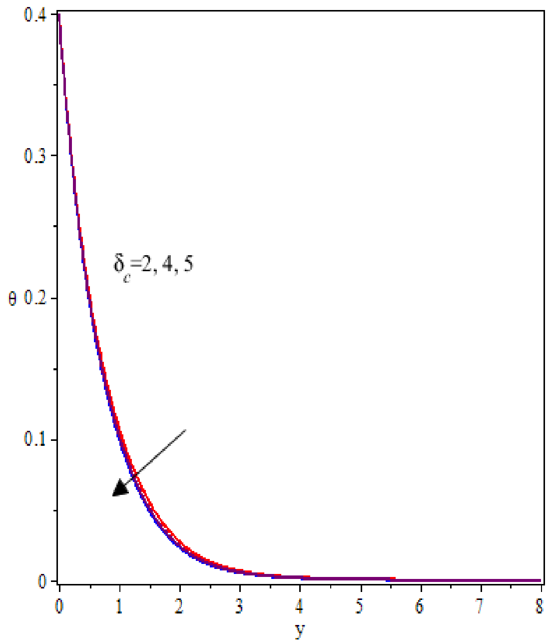

Fig. 10: θ vs. y for δ_c

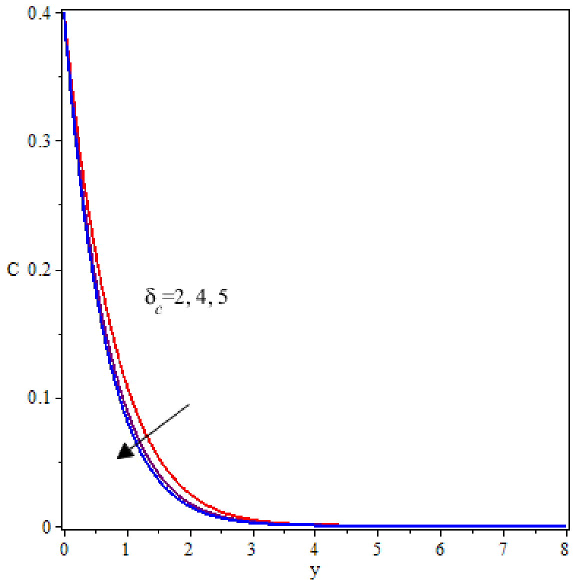

Fig. 11: C vs. y for δ_c

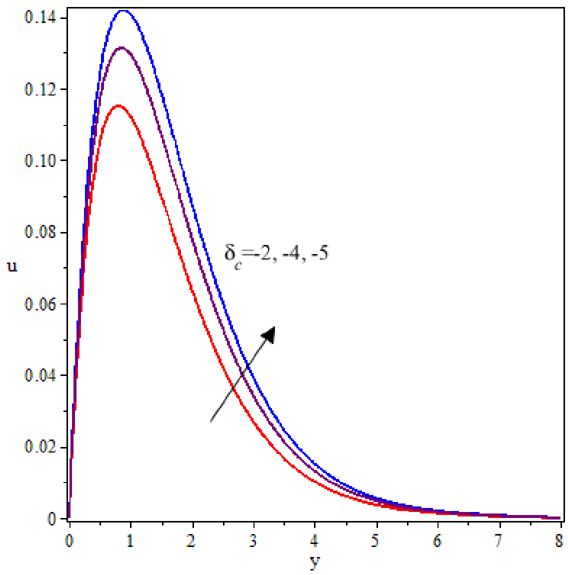

Fig.12: u vs. y for δ_c

We can see from Fig. 9, Fig. 10 and Fig, 11 that as the chemical reaction parameter increases (endothermic), the velocity, temperature and concentration profiles decreases, whereas, this behavior is otherwise in the case of exothermic (decrease in δ_c enhances the velocity, temperature and concentration, Fig. 12, Fig. 13 and Fig. 14, respectively).

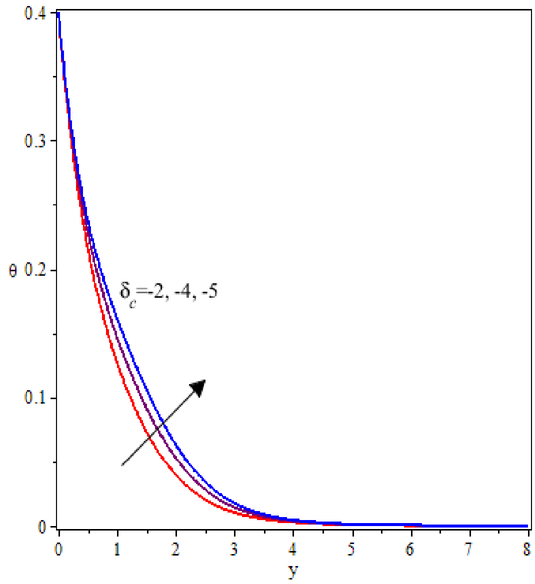

Fig. 13: θ vs. y for δ_c

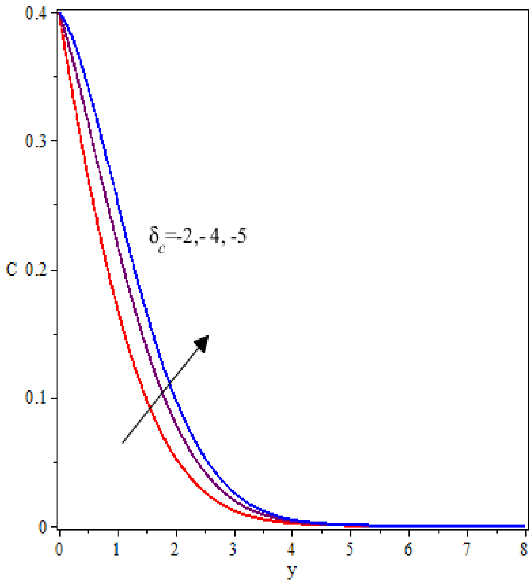

Fig.14: C vs. y for δ_c

The impact of varying the viscoelastic parameter β on velocity u and temperature θ profiles, near and away from the plate are presented in Fig.15 and Fig.16, respectively. It is clear that for smaller value of y, owing to increase of β, both the velocity and the temperature significantly decrease near the plate, but the reverse effect is noticed far away from the plate where considerable variation on velocity and temperature no longer occur.

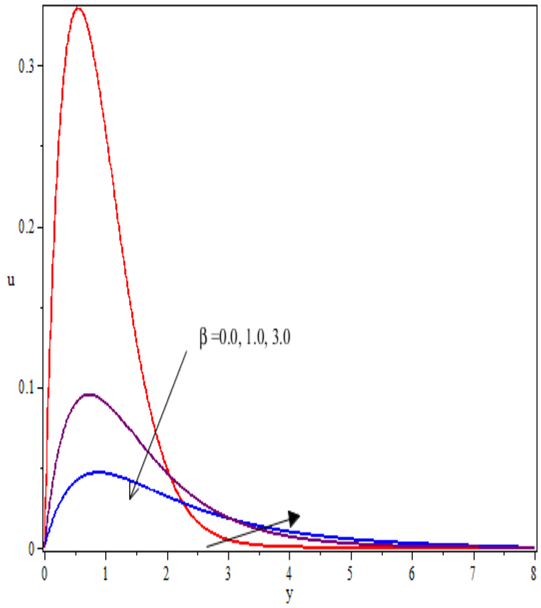

Fig. 15: u vs. y for β

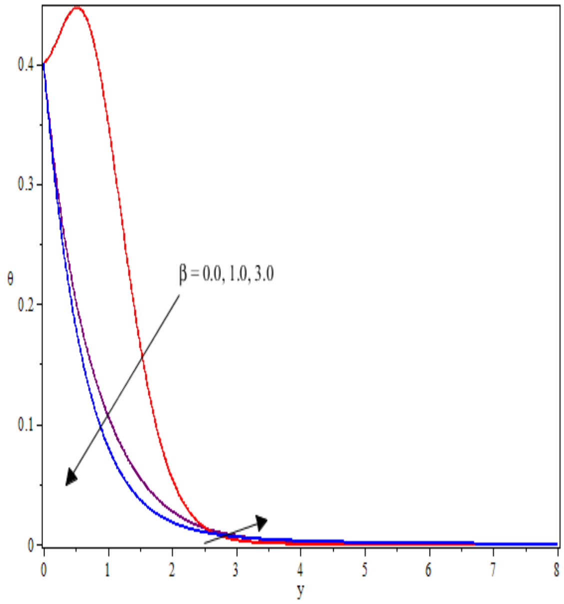

Fig. 16: θ vs. y for β

IV. CONCLUSION

This paper presents the influence of the combined viscous and magnetic dissipations on radiating electrically conducting viscoelastic fluid past an inclined oscillating plate embedded in a porous medium under the homogeneous chemical reaction of first-order in presence of temperature gradient heat sources using the symbolic software MAPLE (Theta Method Scheme). From the graphs shown, we found out that:

- Inclination angle α, viscoelastic parameter β, viscous dissipation parameter E_c, magnetic dissipation parameter J_e, and heat source parameter S have no effect on chemical species concentration since this present work is valid for low species concentration levels, i.e. the concentration of the diffusing species in the binary mixture is assumed to be very small in comparison with the other chemical species.
- The velocity and temperature of the fluid decrease with increase of tilt angle parameter α and heat source parameter S, but reverse effect occurs for Eckert number E_c and Joule heating parameter J_e. The Eckert number strongly raises the velocity and temperature of the fluid in comparison with magnetic dissipation.
- The velocity, temperature and chemical species concentration decrease with increase of chemical reaction parameter δ_c (endothermic), but reverse impact occur for δ_c (exothermic). The impact of δ_c on the temperature profile is very minimal, whereas it is more dominant on velocity and chemical species concentration of the fluid.
- Enhancement of viscoelastic parameter β significantly slow than the fluid motion and the temperature, near the plate, whereas, this behavior is otherwise far away from the plate, where no considerable variation in velocity and temperature occur.

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