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THERMAL DIFFUSION AND ROTATIONAL EFFECTS ON MAGNETO HYDRODYNAMIC MIXED CONVECTION FLOW OF HEAT ABSORBING/GENERATING VISCO- ELASTIC FLUID THROUGH A POROUS CHANNEL

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ABSTRACT

This investigation presents an analytical study on magnetohydrodynamic (MHD), convective flow of a viscoelastic, incompressible, radiative, chemically reactive, electrically conducting and rotating fluid through a porous medium filled in a vertical channel in the presence of thermal diffusion. A magnetic field of uniform strength is applied along the axis of rotation. The fluid is assumed to act on with a periodic time variation of the pressure gradient in upward direction vertically. One of the plates is maintained at non-uniform temperature and the temperature difference of the walls of the channel is assumed high enough that induces heat transfer due to thermal radiation. The analytical solutions are obtained for velocity, temperature and concentration, by solving the dimensionless governing equations using regular perturbation technique. To assess the effects of various parameters involved in the model, two cases of small and large rotations have been considered. Effects of various parameters involved in velocity, temperature, species concentration distributions and the corresponding amplitude and the phase angle of the skin friction, Nusselt number and Sherwood number are shown graphically and discussed in detail.

Keywords: *Visco-elastic fluid, homogeneous chemical reacting, convection, MHD, angular rotation, heat absorption/ generation.*

1. INTRODUCTION

Great attention has drawn on magneto hydrodynamic (MHD) rotating flow of electrically conducting viscoelastic incompressible fluids because of to their significant applications in various branches of fluid dynamics. As there is an increasing interest to study environment, geophysical dynamics that is a branch of fluid dynamics has become an important subject now a day. In geophysics, it is applied to measure and study the positions and velocities with respect to affixed frame of reference on the earth's surface, which rotate with respect to an inertial frame in the presence of its magnetic field. It also finds its applications in astrophysics to study the stellar and solar structure inter planetary, inter stellar matter, solar storms etc. During the last few years, it also finds its application in engineering. As said earlier among the numerous applications of rotating flow in porous media to engineering disciplines like chemical process industry, food processing industry, centrifugation and filtration process and rotating machinery.

In recent years, a number of studies have their place in the literature on the fluid phenomena on earth revolving rotation to a greater or lesser extent. Choudhury et al. (2012) discussed MHD mixed convective heat and mass transfer in a viscoelastic flow past a vertical permeable porous plate with thermal radiation and chemical reaction. Sivraj and Kumar (2012) presented unsteady MHD dusty visco-elastic fluid Couette flow with variable mass diffusion in an irregular channel. Reddy et al. (2010) studied unsteady free convective MHD non-Newtonian fluid flow through an infinite inclined porous plate. Pal and Talukdar (2011) examined combined effects of Joule heating and homogeneous chemical reaction on magnetohydrodynamic mixed convection of a dissipating fluid over a vertical porous plate with thermal radiation. Hayat et al. (2011) employed thermal diffusion and chemical reaction influence on oscillatory three-dimensional flow past an infinite vertical porous plate. Raju et al. (2011) noticed MHD Thermal diffusion natural convection flow. Between heated inclined plates in porous medium. Singh (2012) obtained exact solution of MHD mixed convection flow in rotating vertical channel with heat radiation. Choudhary et al. (2012) presented heat transfer to MHD oscillatory viscoelastic flow in channel filled with porous medium.

Singh (2012) analyzed MHD viscoelastic mixed convection oscillatory flow through a discussed radiation effects on MHD flow past an impulsively started vertical plate with variable heat and mass transfer. Sajid et al. (2010) studied fully developed

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mixed convection flow of a viscoelastic fluid between permeable parallel vertical plates. Pop et al. (2010) assumed the effect of heat generated by an exothermic reaction on the fully developed mixed convection flow is a vertical channel. Bakar and Raizah (2012) considered unsteady MHD mixed convection flow of a varies dissipating micro polar fluids in a boundary layer slip flow regime with Joule heating. Srinivas and Muthuraj (2010) solved effects of thermal radiation and space porosity o MHD mixed convection flow in a vertical channel using Homotopy analysis method. Muthucumaraswamy et al. (2013) examined variable heat and mass diffusion in the presence of rotation on MHD flow past an accelerated vertical plate. Makande (2011) employed MHD mixed convection interface with radiation and nth order chemical reaction past a vertical porous plate embedded in a porous medium. Choudhary et al. (2012) obtained heat transfer to MHD oscillatory viscoelastic flow in a channel filled with porous medium. Singh et al. (2010) presented mixed convection flow past a porous vertical plate in a rotating system with magnetic field. Seth et al. (2012) analyzed effects of Hall current and rotation on hydromagnetic natural convection flow with heat and mass transfer of a heat absorbing fluid with ramped wall temperature. Sing et al. (2012) discussed heat and mass transfer on MHD free convective flow through a vertical porous channel. Ahmed and Batin (2010) investigated analytically MHD radiating mixed convective fluid with viscous dissipative heat. Mohiddin et al. (2010) investigated numerically free convective Walters-B viscoelastic fluid flow along a vertical cone. Dash et al. (2009) considered rotational effects on MHD flow of a visco elastic fluid past an infinite vertical porous plate with heat and mass transfer in the presence of a chemical reaction. Abdul Hakeem et al. (2008) presented an analytic solution of an oscillatory flow through a porous medium with radiation effect on linear analysis method. Mamatha et al. (2015) obtained thermal diffusion effect on MHD micro polar fluid past a semi-infinite vertical porous plate. Mythili et al. (2016) observed that Influence of higher order chemical reaction and non-uniform heat source/sink on casson fluid flow over a vertical cone and flat plate. Sivaraj and Benazir (2015) investigated that unsteady magnetohydrodynamic mixed convective oscillatory flow of casson fluid in a porous asymmetric wavy channel. Prakash et al. (2014) studied that radiation and Dufour effects on unsteady MHD mixed convective flow in an accelerated vertical wavy plate with varying temperature and mass diffusion.

The aim of the present analysis is to investigate thermal diffusion and rotational effects on magnetohydrodynamic mixed convection flow of heat absorbing/generating visco- elastic fluid through a porous channel. The novelty of this study is to consider the presence of thermal diffusion along with homogeneous chemical reaction in a rotating system, which appears to be used in many areas of science and engineering. As far as author's knowledge is concern this phenomenon was not studied earlier, hence we showed interest and attempted to study this work.

2. BASIC EQUATIONS

In order to derive the governing equations from the basic Navier stokes equations for the flows considered here the following assumption are made:

i) The flow considered is unsteady and laminar.
ii) A magnetic field of uniform strength is applied normal to the flow.
iii) The magnetic Reynolds number is taken to be small enough so that the induced magnetic field is neglected.
iv) Hall effect, electrical and polarization effects are neglected.
v) The fluid is optically thin with relatively low density.
vi) The entire system rotates about an axis perpendicular to the plates.
vii) Since plates are infinite so all physical quantities except pressure depend only on z* and t*.

Under the above assumptions the equations of continuity, motion and energy in a rotating frame of reference as:

$$\nabla . V = 0 \tag{1}$$

$$\frac{\partial V}{\partial t} + (V.\nabla V) + 2\Omega \times V = \nabla . \exists - \vartheta_1 \frac{V}{K} + \frac{1}{\rho}(J \times B) + F \tag{2}$$

$$\frac{\partial T^*}{\partial t} + (V.\nabla)T^* = \frac{K}{\rho C_p}\nabla^2 T^* - \frac{\nabla q}{\rho C_p}, \tag{3}$$

$$\frac{\partial C^*}{\partial t} + (V.\nabla)C^* = D\nabla^2 C^* - K_r (C^* - C_1) \tag{4}$$

The last term in equation (2) left hand side is the Coriolis force. In equation (2) on the right side the last term $F = g\beta^*(C^* - C_1) + g\beta(T^* - T_1)$ accounts for the force due to boundary and the second last term is the Lorentz force due to magnetic field B and is given by

$$J \times B = \sigma (V \times B) \times B. \tag{5}$$

In equation (2) first term on the right hand side, $\exists$ is the Cauchy stress tensor and constitute equation for an incompressible homogeneous fluid of second order is

$$\exists = -p^* l + \mu_1 A_1 + \mu_2 A_2 + \mu_3 A_1^2 \tag{6}$$

Here $-p^* l$ is the interdeterminate part of the strees due to constraint of incompressibility μ_1, μ_2, μ_3 are the material constants describing viscosity, elasticity and cross –viscosity respectively. The kinematic A_1, A_2 are the Rivelen Ericson constants defined as

$$A_1 = (\nabla \overline{\nabla) +} (\nabla \overline{\nabla})^T, A_2 = \frac{dA_1}{dt} + A_1(\nabla \overline{\nabla}) + A_2(\nabla \overline{\nabla})^T,$$

Where ∇ denotes the gradient operator and d/dt the material. The modified pressure $p^* = p^\bullet - \frac{\rho}{2}|\Omega \times R|^2$, where R denotes the position vector from the axis of rotation $p^\bullet$, denotes the fluid pressure, J is the current density and all other quantities have their usual meanings and have been defined in the text time to time.

The last term in equation (3) stands for heat due to radiation and is given by

$$\frac{\partial q^*}{\partial z^*} = 4a^* \sigma^* (T^{*4} - T_1^4) \tag{7}$$

For the case of an optically this gray gas. Here a^* is the mean absorption coefficient and σ^* is Stefan –Boltzmann constant. We assume that temperature differences with the flow are

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sufficiently small such that =may be expressed as a linear function of the temperature .This is accomplished by expanding T^{*4} in a Taylor series about T_1 and neglecting higher order terms,

$$T^{*4} = 4T_1^{*2} T^* - 3T_1^4 \tag{8}$$

Substituting (8) into (7) and simplifying we obtain

$$\frac{\partial q^*}{\partial z^*} = 16a^*\sigma^* T_1^{*2}(T^* - T_1) \tag{9}$$

The substitution of equation (9) into the energy equation (3) for the heat due to radiation, we get

$$\frac{\partial T^*}{\partial t^*} + (V.\nabla)T^* = \frac{k}{\rho c_p}\nabla^2 T^* - 16a^*\sigma \frac{T_1^2}{\sigma c_p}(T^* - T_1)$$
(10)

3. FORMULATION OF THE PROBLEM

We consider an unsteady flow of a viscoelastic (second order) incompressible and electrically conducting fluid bounded by two infinite insulated vertical plates distanced apart as shown in fig. A coordinate system is chosen such that the X* -axis is oriented upward along the centerline of the channel and Z* -axis taken perpendicular to the planes of plates lying in Z* $= \frac{\pm d}{2}$ planes. The non-uniform temperature of the plate at Z*= $\frac{+d}{2}$ and the species concentration at the plate Z* $= \frac{-d}{2}$ are respectively assumed to be varying periodically with time. The Z*-axis is considered to be the axis of rotation about which the fluid and plates are assumed to be rotating as a solid body with a constant angular velocity A transverse magnetic field of uniform strength B(0,0,B0) is also applied along the axis of rotation. The velocity may reasonably be assumed with its components along x*, y*, z* directions as V (u*, v*, 0). Since the plates are infinite in x*-direction so all physical quantities except pressure depend only on z*and t*. The equation of continuity (1) is satisfied identically for non-porous plates. A schematic diagram of the physical problem considered is shown figure 1.

$$F(z,t) = F_0(z)e^{it},$$

Using the velocity and the magnetic field distribution as stated above the magneto hydrodynamic (MHD) flow in the rotating channel is governed by following Cartesian equations.

$$\frac{\partial u^*}{\partial t^*} - 2\Omega^* v^* = -\frac{1}{\rho}\frac{\partial p^*}{\partial x^*} + \upsilon_1 \frac{\partial^2 u^*}{\partial z^{*2}} + \upsilon_2 \frac{\partial^3 u^*}{\partial z^{*2}\partial t^*}$$
$$+ g\beta(T^* - T_1) + g\beta^*(C^* - C_1) - \sigma\frac{B_0^2 u^*}{\rho} - \upsilon_1\frac{u^*}{K^*} \tag{11}$$

$$\frac{\partial v^*}{\partial t^*} + 2\Omega^* u^* = -\frac{1}{\rho}\frac{\partial p^*}{\partial y^*} + \upsilon_1 \frac{\partial^2 v^*}{\partial z^{*2}} + \upsilon_2 \frac{\partial^3 v^*}{\partial z^{*2}\partial t^*}$$
$$-\sigma\frac{B_0^2 v^*}{\rho} - \upsilon_1\frac{v^*}{K^*} \tag{12}$$

$$0 = -\frac{1}{\rho}\frac{\partial p^*}{\partial z^*} \tag{13}$$

$$\frac{\partial T^*}{\partial t^*} = \frac{K}{\rho C_p}\frac{\partial^2 T^*}{\partial z^{*2}} - \frac{1}{\rho C_p}\frac{\partial q_r^*}{\partial y^*} - -\frac{Q}{\rho C_p}(T^* - T_1)$$
(14)

$$\frac{\partial C^*}{\partial t^*} = D\frac{\partial^2 C^*}{\partial z^{*2}} + D_1\frac{\partial^2 T^*}{\partial z^{*2}} - K_r(C^* - C_1) \tag{15}$$

where ρ is the density , υ_1 is the visco-elasticity ,p* is the modified pressure, t*is the time , ..is the electric conductivity , g is the acceleration due to gravity , β is volumetric coefficient of thermal expansion, $\beta*$ is the volumetric coefficient of expansion with concentration , k is the thermal conductivity, Cp is the specific heat at constant pressure, D is the molecular diffusivity and Kr is the chemical reaction. Equation (13) shows the constancy of the hydrodynamic pressure along the axis of rotation.

The boundary conditions for the problem are

$$z^* = \frac{-d}{2},$$
$$u^* = v^* = 0, T^* = T_1, C^* = C_1 + (C_2 - C_1)\cos w^* t^* \tag{16}$$

$$z^* = \frac{d}{2},$$
$$u^* = v^* = 0, T^* = T_1 + (T_2 - T_1)\cos w^* t^*, C^* = C_1 \tag{17}$$

Where w* is the frequency of oscillations.

Introducing the following non-dimensional

$$x = \frac{x^*}{d}, y = \frac{y^*}{d}, z = \frac{z^*}{d}, u = \frac{u^*}{\nu}, v = \frac{v^*}{\nu}, \theta = \frac{T^* - T_1}{T_2 - T_1},$$
$$C = \frac{C^* - C_1}{C_2 - C_1}, \theta = \frac{w^* d^2}{\upsilon_1}, \theta = \frac{dp^*}{\rho\upsilon_1\nu}, t = w^* t^*, \tag{18}$$

$$M^2 = \frac{\sigma B_0^2}{\rho},\quad K^{-1} = \frac{\nu_1}{k^*},\; G_r = \frac{g\beta(T_2 - T_1)}{\nu},$$

$$G_m = \frac{g\beta^*(T_2 - T_1)}{\nu},\quad f = \frac{4I_1 d^2}{K}, -\frac{\partial p}{\partial x} = A\cos t$$

$$R = \frac{Q^* d^2 (C_2 - C_2)}{K(T_2 - T_1)},\quad \Gamma = \frac{Qd^2}{K},\quad S_c = \frac{\theta_1}{D},$$

$$K_r = \frac{K_r^* d^2}{\theta_1},\quad S_0 = \frac{D_1(C_2 - C_1)}{\theta_1(T_2 - T_1)}, \alpha^2 = 1 + \nu\omega i,$$

$$w\frac{\partial u}{\partial t} - 2\Omega v = -\frac{\partial p}{\partial x} + \frac{\partial^2 u}{\partial z^2} + \gamma w\frac{\partial^3 u}{\partial z^2 \partial t}$$
$$-(M^2 + \frac{1}{K^1})u + G_r\theta + G_m C \tag{19}$$

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$$w\frac{\partial v}{\partial t}+2\Omega u=-\frac{\partial p}{\partial y}+\frac{\partial^2 v}{\partial z^2}+\gamma w\frac{\partial^3 v}{\partial z^2\partial t}-(M^2+\frac{1}{K^1})v \tag{20}$$

$$wP_r\frac{\partial \theta}{\partial t}=\frac{\partial^2\theta}{\partial z^2}+(F+\Gamma)\theta \tag{21}$$

$$wS_c\frac{\partial C}{\partial t}=\frac{\partial^2 C}{\partial z^2}-S_cK_rC+S_cS_0\frac{\partial^2\theta}{\partial z^2} \tag{22}$$

The boundary conditions in the dimensional from become

$$z=\frac{-1}{2}, u=v=0, \theta=0, C=\cos t \tag{23}$$

$$z=\frac{1}{2}, u=v=0, \theta=\cos t, C=0 \tag{24}$$

We shall assume now that the fluid flows under the influence of pressure gradient varying periodically with time in the X*- axis only is of the form

$$-\frac{\partial p}{\partial x}=A\cos t \text{ and } -\frac{\partial p}{\partial x}=0 \tag{25}$$

Here A is a constant.

4. SOLUTION OF THE PROBLEM

Now combine equations (19) and (20) into single equation by introducing a complex F= u+iv, get

$$w\frac{\partial F}{\partial t}+2i\Omega F=A\cos t+\frac{\partial^2 F}{\partial z^2}+\gamma w\frac{\partial^3 F}{\partial z^2\,\partial t}$$
$$-(M^2+\frac{1}{K})F+G_r\theta+G_mC \tag{26}$$

In order to solve the problem, it is convenient to adopt complex notations and assume the solution of the problem as

$$F(z,t)=F_0(z)e^{it}, \theta(z,t)=\theta_0(z)e^{it}, C(z,t)=C_0(z)e^{it},$$
$$-\frac{\partial p}{\partial x}=A\cos t=\mathrm{Ae}^{it} \tag{27}$$

With corresponding boundary conditions as

$$z=\frac{-1}{2}, F=0, \theta=0, C=\cos t \tag{28}$$

$$z=\frac{1}{2}, F=0, \theta=\cos t, C=0 \tag{29}$$

The boundary conditions (28) and (29) in complex notations can also be written as

$$z=\frac{-1}{2}, F=0, \theta=0, C=e^{it} \tag{30}$$

$$z=\frac{1}{2}, F=0, \theta=e^{it}, C=0 \tag{31}$$

Substituting expressions (27) in the equations (26),(21) and (22), we get

$$\alpha^2\frac{\partial^2 F_0}{\partial z^2}-b_1^2F_0=-A-G_r\theta_0-G_mC_0, \tag{32}$$

$$\frac{\partial^2\theta_0}{\partial z^2}-k_2^2\theta_0=0, \tag{33}$$

$$\frac{\partial^2 C_0}{\partial z^2}-k_8^2C_0=k_9\theta_0^2, \tag{34}$$

The transformed boundary conditions reduce to

$$\begin{aligned}&z=\frac{-1}{2}, \quad F_0=0, \quad \theta_0=0, \quad C_0=1,\\&z=\frac{1}{2}, \quad F_0=0, \quad \theta_0=1, \quad C_0=0,\end{aligned} \tag{35}$$

The ordinary differential equations (32), (33) and (34) and are solved under the boundary conditions (35) and for velocity, temperature and species concentration fields. The solution of the problem is obtained as

$$F(z,t)=(b_{23}e^{m_1z}+b_{20}e^{-m_1z}+b_6+b_9e^{k_2z}+b_{10}e^{-k_2z}+b_{11}e^{k_8z}+b_{12}e^{-k_8z})e^{it}, \tag{36}$$

$$\theta(z,t)=(k_4e^{k_2z}+k_5e^{-k_2z})e^{it}, \tag{37}$$

$$C(z,t)=(k_{22}e^{k_8z}+k_{19}e^{-k_8z}+k_{13}e^{k_2z}+k_{14}e^{-k_2z})e^{it}, \tag{38}$$

The primary velocity is given by the real part of complex function F(z,t).

From the velosity field we can now obtain the skin-friction τ at the left plate in terms of its amplitude and phase angle as

$$\tau_L=\left(\frac{\partial F}{\partial z}\right)_{z=-\frac{1}{2}}=|F|\cos(t+\varphi) \tag{39}$$

(40)

$$F_r+iF_i=b_{23}m_1e^{\frac{-m_1}{2}}-b_{20}m_1e^{\frac{m_1}{2}}+b_9k_2e^{\frac{-k_2}{2}}$$
$$-b_{10}k_2e^{\frac{k_2}{2}}+b_{11}k_8e^{\frac{-k_8}{2}}-b_{12}k_8e^{\frac{k_8}{2}} \tag{40}$$

The amplitude is $|F|=\sqrt{F_i^2+F_r^2}$ and the phase angle $\varphi=\tan^{-1}\left(\frac{F_i}{F_r}\right)$. (41)

From the temperature field given in equation (37) the heat transfer coefficient Nusselt number Nu interms of its amplitude and phase angle can be obtained as

$$Nu=\left(\frac{\partial\theta}{\partial z}\right)_{z=-\frac{1}{2}}=|H|\cos(t+\psi) \tag{42}$$

Where $H_r+iH_i=k_4k_2e^{-\frac{k_2}{2}}-k_5k_2e^{\frac{k_2}{2}}$ (43)

The amplitude $|H|$ and the phase angle ψ of the heat transfer coefficient Nusselt number Nu are given by

$|H|=\sqrt{H_i^2+H_r^2}$ and

$\psi=\tan^{-1}\left(\frac{H_i}{H_r}\right)$ respectively. (44)

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Similarly ,the amplitude and the phase angle at the left plate (z=0.5) of the Sherwood number Sh
can be obtained from eqution (39) for the species concentration as

$$Sh = \left(\frac{\partial C}{\partial z}\right)_{z=-\frac{1}{2}} = \left|C\right| \cos(t+\xi) \tag{45}$$

Where $C_r + iC_i = k_{22}k_8 e^{-\frac{k_8}{2}} - k_{19}k_8 e^{\frac{k_8}{2}} + k_{13}k_2 e^{-\frac{k_2}{2}} - k_{14}k_2 e^{\frac{k_2}{2}}$ (46)

The amplitude $\left|C\right|$ and the phase angle ξ of the heat tansfer coeffient Shrwood number Sh are given by

$\left|C\right| = \sqrt{C_i^{\,2} + C_r^{\,2}}$ and

$\xi = \tan^{-1}\left(\frac{C_i}{C_r}\right)$ respectively. (47)

5. RESULTS AND DISCUSSION

When the entire system rotates about an axis perpendicular to the planes of the plates The MHD convective flow in an infinite vertical channel with transverse magnetic field is analyzed. An exact solution of the problem is obtained in the presence of chemical reaction and thermal radiation. The velocity, temperature and species concentration field and the shear stress, Nusselt number and Sherwood number in terms of their amplitudes and phase angles are evaluated numerically for different sets of the values of rotation parameter Ω , visco-elastic parameter γ ,Hartmann number M ,Grashof number Gr, modified Grashof number Gm, Prandtl number Pr, radiation parameter f, Schmidt number Sc, reaction parameter Kr, pressure gradient A, the frequency of oscillations ω, heat absorbing/generating α , radiation parameter (F=f) and Soret number So. To be more realistic the two values Pr=0.7 and 7of the Prandtl number chosen to represent air and water and that of the Schmidt number Sc=0.22 and 0.94 represent Hydrogen and Carbon dioxide respectively. These numerical values are then shown graphically to assess the effect of each parameter for the two cases of small Ω =10 and large Ω =20 rotations. Figures 1-15 demonstrates the variations of the fluid velocity under the efects of different parameters. Figure 1 shows the effect of rotation parameter on the velocity distribution. It is noticed that the primary velocity decreases with increasing values of rotation parameter but seconadry velocity reverse effect is observed in the presence of rotation parameter. Figure 2 depicts the effect of Hartmann number on the velocity distribution. It can be seen that the primary velocity decreases with increasing values of Hartmann number but secondary velocity is noted reverse effect in the presence of Hartmann number. Figure 3 displays the effect of Schmidt number on the velocity distribution. It is seen that the primary velocity decreases with increasing values of Schmidt number but secondary velocity increases. Figure 4 exhibits the effect of frequency on the velocity distribution. It is observed that both primary velocity and secondary velocity decreases with increasing values of frequency. Figure 5 demensrrates the effect of reaction parameter on the velocity distribution. It is shows that primary velocity decreases with increasing values of reaction parameter but secondary velocity increases in presence of reaction parameter. Figure 6 presents the effect of viscoelastic parameter on the velocity distribution. It is revealed that primary velocity and secondary velocity reverse trend in the presence of viscoelastic parameter. Figure 7 illustrates the effect of Prandtl number on the velocity distribution. It show that primary velocity and secondary velocity opposite effect in the presence of Prandtl number. Figures 8 & 9 depict the influence of modified Grashof number and Grashof number on velocity. It can be seen that primary velocity increases for rising values of both the numbers but secondary velocity decreases. Figure 10 shows the effect of Soret number on the velocity distribution. It is evident that primary velocity increases with increasing values of Soret number but secondary velocity decreases in the presence of Soret number. Figure 11 depicts the effect of pressure gradient on the velocity distribution. It is noticed that both primary velocity and secondary velocity increases with increasing values of pressure gradient. Figure 12 displays the effect of porous medium on the velocity distribution. It can be seen that primary velocity increases with increasing values of porous medium but secondary velocity decreases for the increasing values of porous medium. Figure 13 exhibits the effect of heat absorbing on the velocity distribution. It is observed that both primary and secondary velocity decreases with increasing values of heat absorbing parameter. Figure 14 presentes the effect of heat generating on the velocity distribution. It is observed that both primary velocity and secondary velocity decreases with increasing values of heat generating parameter. Figure 15 shows the effect of radiation parameter on the velocity distribution. It is observed that primary velocity decreases with the increasing values of radiation parameter but secondary velocity reveres effect is observed in the presence of radiation parameter.

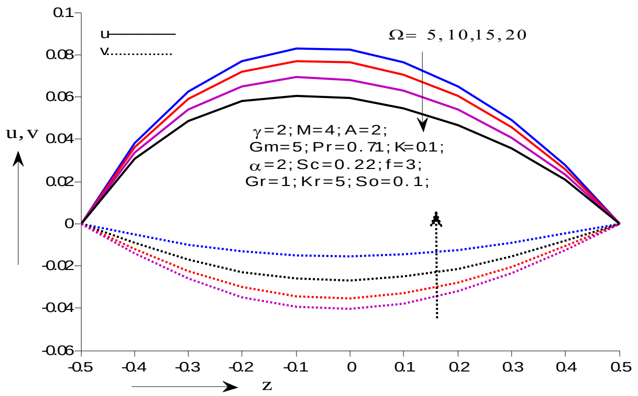

Fig. 1 Effect of rotation parameter on primary velocity and secondary velocity

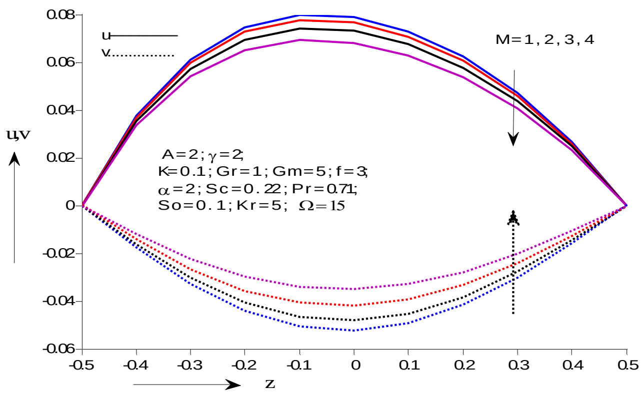

Fig.2 Effect of Hartmann number on primary velocity and secondary velocity

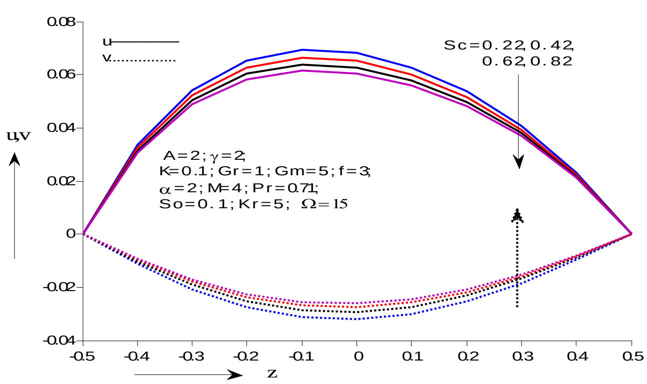

Fig. 3 Effect of Schmidt on primary velocity and secondary velocity

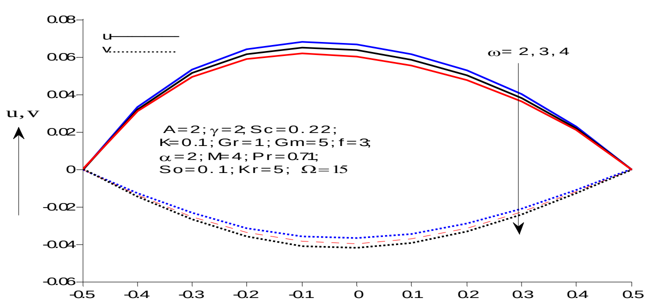

Fig. 4 Effect of frequency of oscillations on primary velocity and secondary velocity

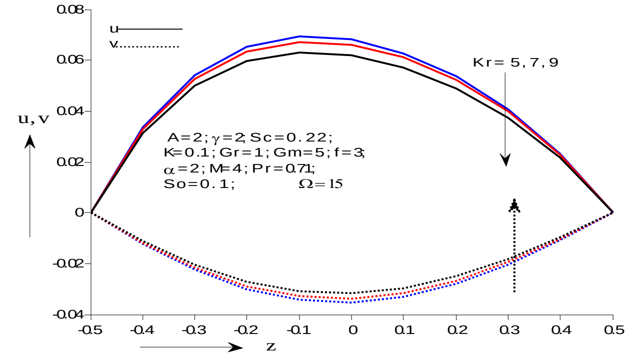

Fig. 5 Effect of reaction parameter on primary velocity and secondary velocity

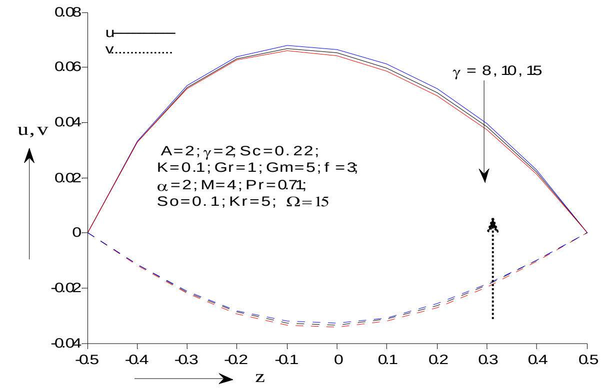

Fig. 6 Effect of viscoelastic parameter on primary velocity and secondary velocity

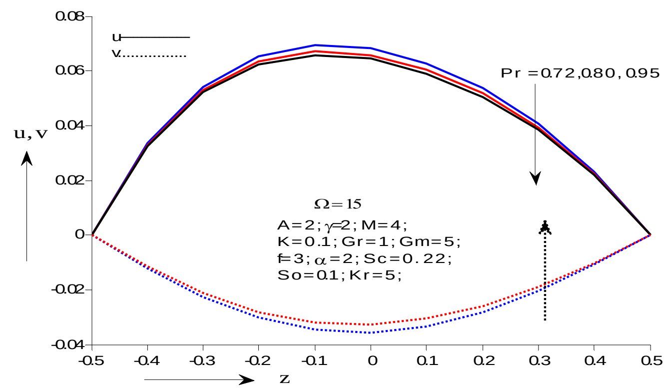

Fig. 7 Effect of Prandtl on primary velocity and secondary velocity

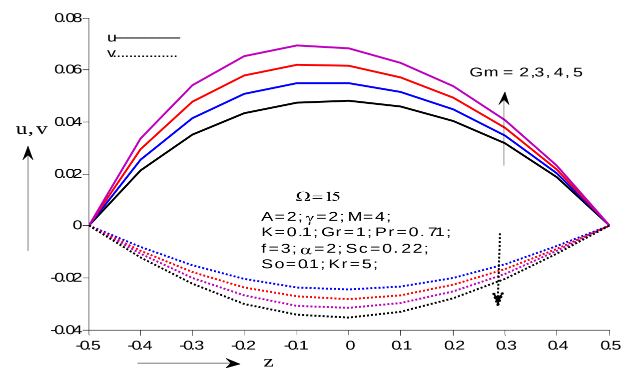

Fig. 8 Effect of modified Grashof number on primary and secondary velocity

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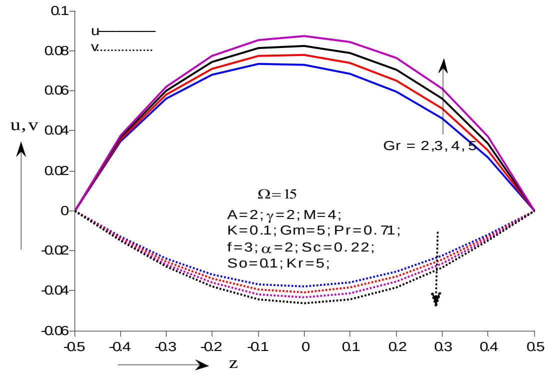

Fig. 9 Effect of Grashof number on primary velocity and secondary velocity

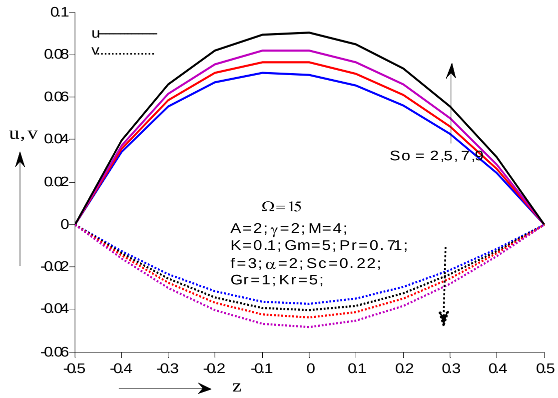

Fig. 10 Effect of Sorret number on primary velocity and secondary velocity

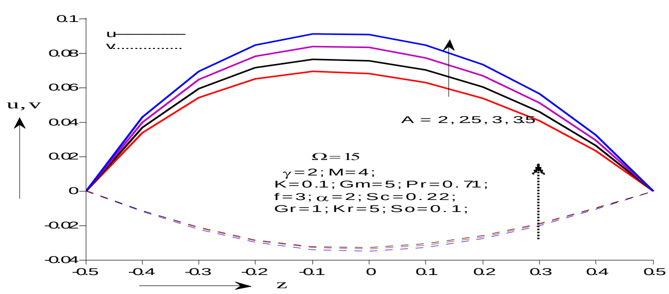

Fig. 11 Effect of pressure gradient on primary velocity and secondary velocity

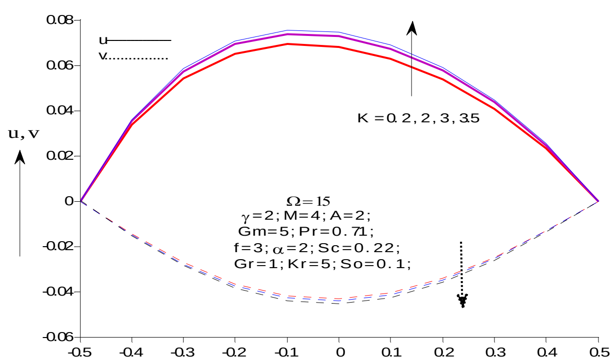

Fig. 12 Effect of porous medium on primary velocity and secondary velocity

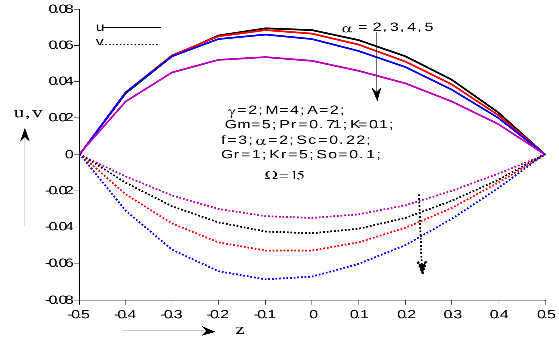

Fig. 13 Effect of Heat absorbing on primary velocity and secondary velocity

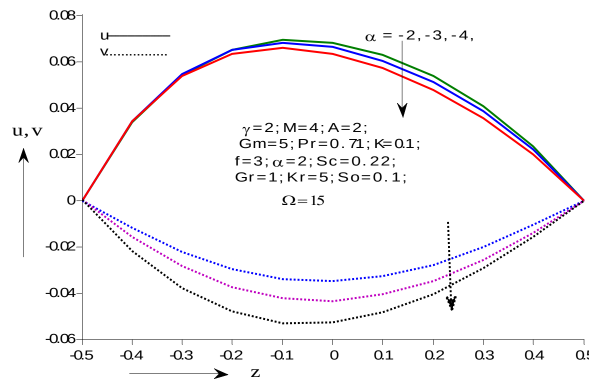

Fig. 14 Effect of Heat genarating on primary velocity and secondary velocity

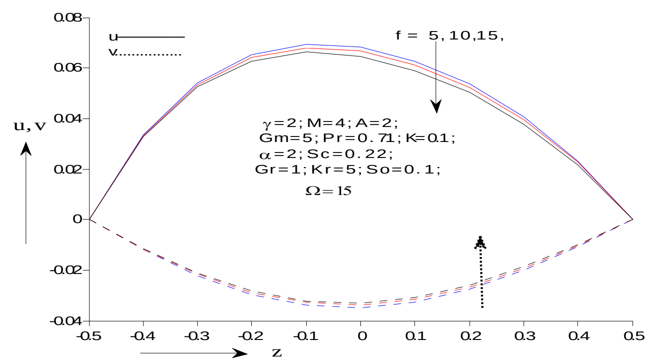

Fig. 15 Effect of radiation parameter on primary velocity and secondary velocity

Figures 16-19 demonstrates the variations of the fluid temparater under the effects of different parameters. Figure 16 shows the effect of radiation parameter on the temperature distribution. It is noticed that temparature decreases with increasing values of radiation parameter for both small (Ω =10) and large (Ω =20) rotations of the system. Figure 17 depicts the effect of viscoelastic parameter on the temperature distribution. It is seen that temparature decreases with increasing values of viscoelastic parameter for both small (Ω =10) and large (Ω =20) rotations of the system. Figure 18 displays the effect of Prandtl number on the temperature distribution. It is perceived that temparature decreases with increasing values of Prandtl number for both small (Ω =10) and large (Ω =20) rotations of the system. Figure 19 presents the effect of frequency of oscillations on the temperature distribution. It is observed that temparature decreases with increasing values of frequency of oscillations for both small (Ω =10) and large (Ω =20) rotations of the system.

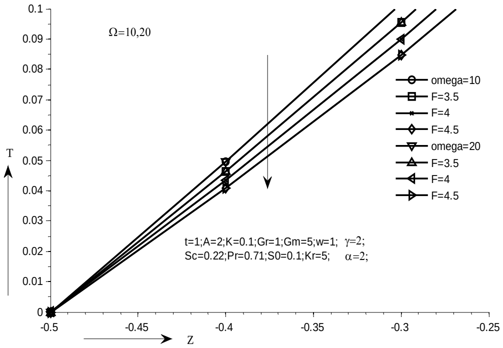

Fig. 16 Effect of radiation parameter on temperature

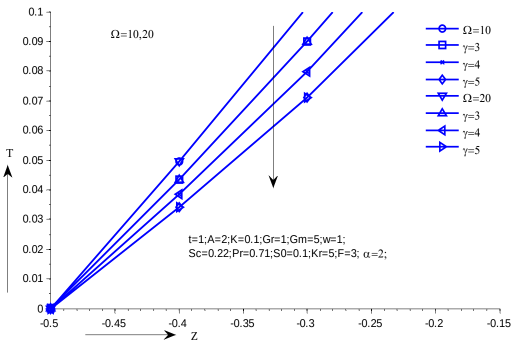

Fig. 17 Effect of viscoelastic on temperature

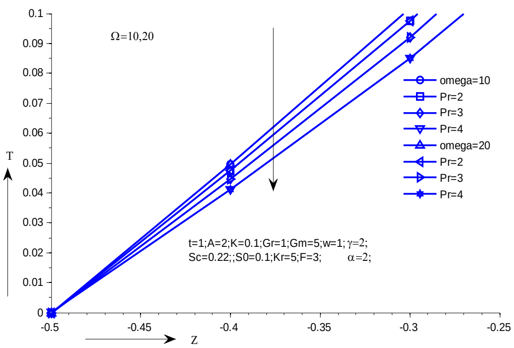

Fig. 18 Effect of Prandtl number on temperature

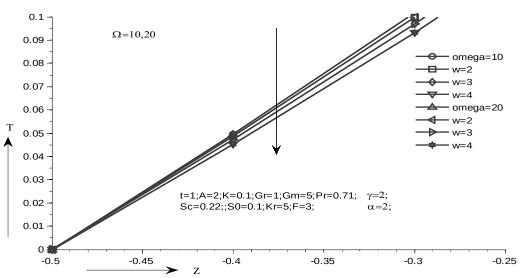

Fig.19 Effect of frequency of oscillations on temperature

Figures 20-25 demonstrates the variations of the fluid concentration under the effects of different parameters. Figure 21 shows the effect of frequency of oscillations on the concentration distribution. It is noticed that concentration decreases with increasing values of frequency of oscillations for both small (Ω =10) and large (Ω =20) rotations of the system.

Figure 21 dispicts the effect of Schmidt number on the concentration distribution. It is seen that concentration decreases with increasing values of Schmidt number for both small (Ω =10) and large (Ω =20) rotations of the system. Figure 22 displays the effect of reaction parameter on the concentration distribution. It is shows that concentration decreases with increasing values of reaction parameter for both small (Ω =10) and large (Ω =20) rotations of the system. Figure 23 exhibites the effect of Soret number on the concentration distribution. It is observed that concentration increases with increasing values of Soret number for both small (Ω =10) and large (Ω =20) rotations of the system. Figure 24 illustrates the effect of Prandtl number on the concentration distribution. It is perceived that the concentration increases with increasing values of Prandtl number for both small (Ω =10) and large (Ω =20) rotations of the system. Figure 25 presents the effect of viscoellastic parameter on the concentration distribution. It shows that concentration increases with increasing values of viscoelastic parameter for both small (Ω =10) and large (Ω =20) rotations of the system.

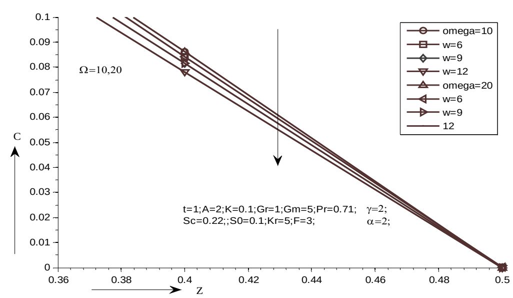

Fig. 20 Effect of frequency of oscillations on concentration

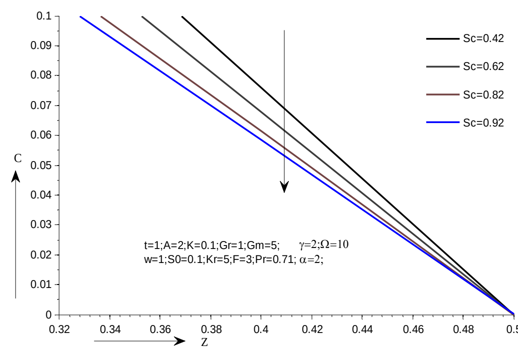

Fig. 21 Effect of Schmidt number on concentration

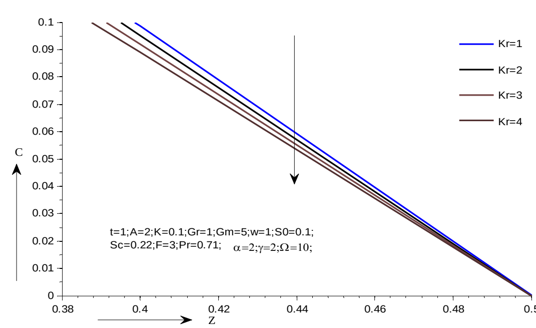

Fig. 22 Effect of reaction parameter on concentration

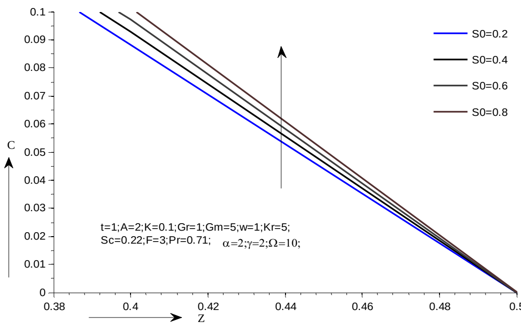

Fig. 23 Effect of Soret number on concentration

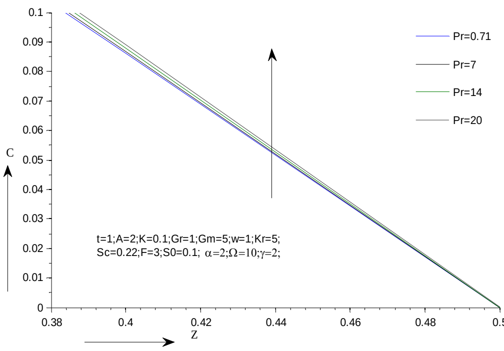

Fig. 24 Effect of Prandtl number on concentration

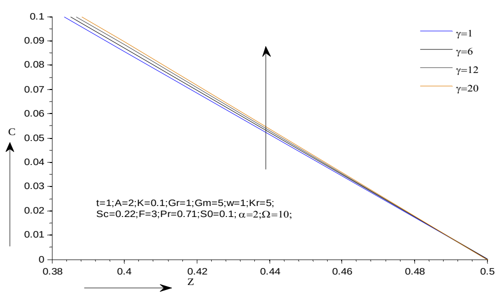

Fig. 25 Effect of viscoelastic parameter on concentration

From table1 it is noticed that skin friction increase due to an increase in Grashof number. From table 2 it is observed that skin friction increase due to an increase in modified Grashof number. From table 3 it is clear that skin friction decrease due to an increase in Hartmann number. From table 4 it is noticed that the skin friction increase due to an increase in porous medium. From table 5 it is observed that the skin friction decrease due to an increase in rotation parameter. From table 6 it is clear that both the skin friction and Nusselt number decreases, and Sherwood number increase due to an increase in radiation parameter. From table 7 it is noticed that both the skin friction and Sherwood number decreases due to an increase in Schmidt number. From table 8 it is observed that both the skin friction and Sherwood number increases due to an increase in Soret number. From table 9 it is cleared that the skin friction increases due to an increase in heat absorption. From table 10 it shows that the skin friction increases due to an increase in heat generation. From table 11it noted that both the skin friction and Nusselt number decreases, and Sherwood number increase due to an increase in visco-elastic parameter. From table 12 it is observed that the skin friction, Nusselt number and Sherwood number decreases due to an increase in frequency of oscillation. From table 13it is noticed that the skin friction, Nusselt number decreases and Sherwood number increase due to an increase in Prandtl number. From table 14 it is clear that the skin friction increase due to an increase in pressure gradient. From table 15 it is noted that both the skin friction and Sherwood number decreases due to an increase in reaction parameter.

Table: 1 Effect of Grashof number on skin friction, Nusselt number and Sherwood number

Gr	τ	N_u	S_h
2	0.4310	0.3008	-1.3350
3	0.4390	0.3008	-1.3350
4	0.4475	0.3008	-1.3350
5	0.4557	0.3008	-1.3350

Table: 2 Effect of modified Grashof number on skin friction, Nusselt number and Sherwood number

Gm	τ	N_u	S_h
1	0.2112	0.3008	-1.3350
2	0.2641	0.3008	-1.3350
3	0.3170	0.3008	-1.3350
4	0.3699	0.3008	-1.3350

Table: 3 Effect of magnetic parameter on skin friction, Nusselt number and Sherwood number

M	τ	N_u	S_h
1	0.4530	0.2364	-1.2711
2	0.4421	0.2364	-1.2711
3	0.4253	0.2364	-1.2711
4	0.4122	0.2364	-1.2711

Table: 4 Effect of permeability parameter on skin friction, Nusselt number and Sherwood number

K	τ	N_u	S_h
0.2	0.4442	0.4920	-1.3395
0.4	0.4544	0.4920	-1.3395
0.3	0.4579	0.4920	-1.3395
0.4	04603	0.4920	-1.3395

Table: 5 Effect of rotation parameter on skin friction, Nusselt number and Sherwood number

Ω	τ	N_u	S_h
5	0.4257	0.4920	-1.3395
10	0.4919	0.4920	-1.3395
20	0.3703	0.4920	-1.3395
30	0.3256	0.4920	-1.3395

Table: 6 Effect of radiation parameter on skin friction, Nusselt number and Sherwood number

F	τ	N_u	S_h
1	0.4240	0.3807	-1.3370
2	0.4234	0.3377	-1.3359
3	0.4228	0.3008	-1.3350
4	0.4223	0.2690	-1.3342

Table: 7 Effect of Schmidt number on skin friction, Nusselt number and Sherwood number

Sc	τ	N_u	S_h
0.22	0.4257	0.4920	-1.3395
0.44	0.4144	0.4920	-1.6201
0.62	0.4047	0.4920	-1.8873
0.82	0.3962	0.4920	-2.1787

Table:8 Effect of Schmidt number on skin friction, Nusselt number and Sherwood number

S_0	τ	N_u	S_h
0.2	0.4265	0.4920	-1.3359
0.4	0.4281	0.4920	-1.3288
0.6	0.4297	0.4920	-1.3216
0.8	0.4314	0.4920	-1.3144

Table: 9 Effect of heat absorption parameter on skin friction, Nusselt number and Sherwood number

α	τ	N_u	S_h
1	0.3966	0.4920	-1.3395
2	0.4257	0.4920	-1.3395
3	0.4581	0.4920	-1.3395
4	0.5934	0.4920	-1.3395

Table: 10 Effect of heat generation parameter on skin friction, Nusselt number and Sherwood number

α	τ	N_u	S_h
-1	0.3966	0.4920	-1.3395
-2	0.4257	0.4920	-1.3395
-3	0.4581	0.4920	-1.3395
-4	0.5934	0.4920	-1.3395

Table: 11 Effect of visco- elastic parameter on skin friction, Nusselt number and Sherwood number

γ	τ	N_u	S_h
1	0.4268	0.5653	-1.3412
2	0.4257	0.4920	-1.3395
3	0.4248	0.4315	-1.3381
4	0.4240	0.3807	-1.3370

Table: 12 Effect of frequency of oscillations on skin friction, Nusselt number and Sherwood number

ω	τ	N_u	S_h
2	0.4239	0.4824	-1.3418
3	0.4217	0.4671	-1.3457
4	0.4192	0.4468	-1.3510
5	0.4164	0.4223	-1.3578

Table: 13 Effect of Prandtl number heat generation parameter on skin friction, Nusselt number and Sherwood number

Pr	τ	N_u	S_h
0.71	0.4608	0.4920	-1.3395
0.91	0.4607	0.4899	-1.3395
1.5	0.4604	0.4810	-1.3393
5	0.4564	0.2755	-1.3355

Table: 14 Effect of pressure gradient on skin friction, Nusselt number and Sherwood number

A	τ	N_u	S_h
1	0.3507	0.4920	-1.3395
2	0.4257	0.4920	-1.3395
3	0.5007	0.4920	-1.3395
4	0.5758	0.4920	-1.3395

Table: 15 Effect of chemical reaction parameter on skin friction, Nusselt number and Sherwood number

Kr	τ	N_u	S_h
1	0.4347	0.3008	-1.0631
2	0.4315	0.3008	-1.1339
3	0.4285	0.3008	-1.2027
4	0.4256	0.3008	-1.2697

6. CONCLUSIONS

The non-dimensional governing equations of the problem are solved by using perturbation method. The variations in the velocity, temperature and concentration with the effects of various parameters encountered in the problem are studied through graphs. In addition, the effects some of the above parameters on skin friction, Nusselt number and Sherwood number are observed.

- The fluid velocity increases with the increasing values of Grashof number, modified Grashof number, porosity parameter, Soret number and pressure gradient, but a reverse trend is found in the case of Hartmann number, frequency of oscillations, reaction parameter, Schmidt number, viscoelastic parameter, Prandtl number and rotation parameter.
- The fluid velocity decreases with increasing values of heat absorbing $(\alpha = 4.5 \text{ above})$ for both small (Ω =10) and large (Ω =20) rotations of the system. The velocity increases with decreasing values of $(\alpha = -1 \text{ to } -4)$ heat generating for small (Ω =10) rotations of the system but velocity decreases with decreasing values

($\alpha = -5$ below) of heat generating for small (Ω =10) rotations of the system. The velocity decreases with the decreasing values of ($\alpha = -1$ below) heat generating for large (Ω =20) rotations of the system.

- The fluid temperature decreases with the increasing values of Prandtl number, rotation parameter, radiation parameter and frequency of oscillations.
- The fluid concentration increases with the increasing values of Soret number, Prandtl number and viscoelastic parameter, but a reverse trend is found in the case of frequency of oscillations, reaction parameter, and Schmidt number.
- Skin friction decreases for increasing values of Soret.
- Nusselt number increases with increasing values of absorption parameter and radiation parameter, but an opposite behavior is noticed in the case of Dufour number.
- The rate of mass transfer is enhanced with increasing values of Schmidt number and decreasing values of Soret number.

APPENDIX

$$k_1 = f + \Gamma, k_2^2 = k_1 + i\omega P_r, k_3 = e^{\frac{k_2}{2}} - e^{-k_2},$$

$$k_4 = \frac{1}{k_3}, k_5 = -e^{-k_2} k_4, k_6 = k_4 k_2^2, k_7 = k_5 k_2^2,$$

$$k_8^2 = S_c K_r + i\omega S_c, k_9 = -S_c S_0, k_{10} = k_9 k_6,$$

$$k_{11} = k_9 k_6, k_{12} = k_2^2 - k_8^2, k_{13} = \frac{k_{10}}{k_{12}}, k_{14} = \frac{k_{11}}{k_{12}},$$

$$k_{15} = e^{k_8} - e^{-k_8}, k_{16} = e^{-\frac{k_2}{2}+\frac{k_8}{2}} - e^{\frac{k_2}{2}-\frac{k_8}{2}},$$

$$k_{17} = e^{\frac{k_2}{2}+\frac{k_8}{2}} - e^{\frac{-k_2}{2}-\frac{k_8}{2}}, k_{18} = e^{\frac{k_2}{2}} - k_{13}k_{16} - k_{14}k_{17},$$

$$k_{19} = \frac{k_{18}}{k_{15}}, k_{20} = -e^{\frac{-k_8}{2}} k_{19} - e^{\frac{k_2}{2}} k_{13} - e^{\frac{-k_2}{2}} k_{14},$$

$$k_{21} = e^{\frac{k_8}{2}}, k_{22} = \frac{k_{20}}{k_{21}}, \alpha^2 = 1 + \nu\omega i,$$

$$b_1 = \sqrt{M^2 + \frac{1}{K} + \omega i + 2i\Omega}, b_2 = G_r k_4 + G_m k_{13},$$

$$b_3 = G_r k_5 + G_m k_{14}, b_4 = G_m k_{22}, b_5 = G_m k_{19},$$

$$m_1 = \frac{b_1}{2}, b_6 = \frac{A}{b_1^2}, b_7 = \alpha^2 k_2^2 - b_1^2, b_8 = \alpha^2 k_8^2 - b_1^2,$$

$$b_9 = \frac{-b_2}{b_7}, b_{10} = \frac{-b_3}{b_7}, b_{11} = \frac{-b_4}{b_8}, b_{12} = \frac{-b_5}{b_8}, b_{13} = (e^{\frac{m_1}{2}} - e^{\frac{-m_1}{2}}),$$

$$b_{14} = (e^{\frac{-k_2}{2}+\frac{m_1}{2}} - e^{\frac{k_2}{2}-\frac{m_1}{2}}), b_{15} = (e^{\frac{k_2}{2}+\frac{m_1}{2}} - e^{\frac{-k_2}{2}-\frac{m_1}{2}}),$$

$$b_{16} = (e^{\frac{-k_8}{2}+\frac{m_1}{2}} - e^{\frac{k_8}{2}-\frac{m_1}{2}}), b_{17} = (e^{\frac{k_8}{2}+\frac{m_1}{2}} - e^{\frac{-k_8}{2}-\frac{m_1}{2}}),$$

$$b_{18} = (e^{m_1} - e^{-m_1}), b_{19} = b_6 b_{13} + b_9 b_{14} + b_{10} b_{15} + b_{11} b_{16} + b_{12} b_{17},$$

$$b_{21} = b_{20} e^{\frac{-m_1}{2}} + b_6 + b_9 e^{\frac{k_2}{2}} + b_{10} e^{\frac{-k_2}{2}} + b_{11} e^{\frac{k_8}{2}} + b_{12} e^{\frac{-k_8}{2}},$$

$$b_{20} = \frac{-b_{19}}{b_{18}}, b_{22} = e^{\frac{m_1}{2}}, b_{23} = \frac{-b_{21}}{b_{22}}.$$

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