Reprint ISSN 0973-9424

INTERNATIONAL JOURNAL OF MATHEMATICAL SCIENCES AND ENGINEERING APPLICATIONS

(IJMSEA)

ASCENT PUBLICATION
@
ASCENT
PUNE, INDIA

www.ascent-journals.com

International J. of Pure & Engg. Mathematics (IJPEM)
ISSN 2348-3881, Vol. 16 No. I (June, 2022), pp. 22-41

STUDY OF THERMAL RADIATION AND CHEMICAL REACTION ON MHD FREE CONVECTION FLOW IN COUTTE FLOW EMBEDDED WITH POROUS MEDIA

KHALID BAKHEET MAHAMMED AL THUBANI[1] AND N. AMEER AHAMMAD[2]
[1,2] Department of Mathematics, Faculty of Science,
P. O. Box 741, Tabuk, 71491, Saudi Arabia.

Abstract

In this work, we study the effect of thermal radiation and chemical radiation on MHD free convection flow in Coutte flow embedded with porous medium. Making use of Perturbation technique, we find velocity, temperature and concentration profiles which are examined through the graphs. The skin friction, Nusselt number and Sherwood number are evaluated analytically and computationally discussed.

1. Introduction

In the recent days a considerable attention has been gained by the magnetohydrodynamic Heat transfer enhancement in electronic, aircraft, medical and experimental industries needs using efficient methods in equipment. In these industries, due to various dimensions of equipment, used systems do not have the capability of transferring critical heat flux caused by low effective methods. The mass transport reasoned with the temperature gradient is known Soret effects, whereas the heat transport reasoned

Keywords : *MHD, Thermal Radiation, Chemical reatction, Porous medium.*

with the temperature gradient is known Soret effects, whereas the heat transport reasoned with the concentration gradient is known as Dufour effects. Towards attained most significant concepts of costs and energies, intensification of heat transport played an extremely requisite role. The present developments in the field of science and technology are levitating the demands for exceptional characteristic packed together machines with the better performances, speed and accurate rolling, and extended life span. Therefore, the scholars and scientists congregated to working on the thermal organization of heat transport machines. The curiosity of combined heat and mass transport with natural convection in a fluid saturated porous medium intervenes in countless manufacturing, technical and industrial companies such as hydro-geological, earth sciences, electronically applications getting cold through fans, terrestrial heat power exploitation, petroleum repositories, and invent of steel undulating and atomic strength factories. An extensive version of the existing in sequence is granted in the modern researchers Neild and Bejan [1] and, Ingham and Pop [2]. Current years, substantial emphasis committed towards investigate the hydromagnetic flows for heat and mass transport since for claims through physics of the earth, aeronautical studies, and engineering in chemistry. Palani and Srikanth [3] premeditated the hydromagnetic flow of an electrically conducting fluid across a semi-infinite vertical plate under the effect of magnetic field. Makinde [4] explored the MHD boundary layer flow with heat and mass transport past a moving vertical plate in the occurrence of magnetic field. Narayana [5], discussed to study the effects of radiation absorption and first-order chemical reaction on unsteady mixed convective flow of a viscous incompressible electrically conducting fluid through a porous medium of variable permeability between two long vertical non conducting wavy channels in the presence of heat generation. Elbashbeshy et al. [6], addressed the results of heat radiation as well as magnetic field on unsteady combined convective flow along with heat transport through an exponentially stretching surface by suction in the existence of inside warmth production or else assimilation. Hakeem et al. [7], investigated second order MHD slip flow of nanofluid past a permeable surface. Baag et al. [8], examined entropy production investigation for MHD flow of visco-elastic fluid over a absorbent stretching sheet. Kalidas et al. [9], examined the flow of Jeffrey fluid through a stretching sheet with heat transfer and also surface slip. Umawati et al. [10] The unprotected progress of coarse liquid were explored through a composite frequency, half of which is loaded up with the porous medium. Ajibade and Jha [11] presented the effects of suction and injection on hydrodynamics of oscillatory fluid through parallel plates. The same authors extended the problem to heat generating/absorbing fluids in Ref. [12] while in Ref. [13] the effect of viscous dissipation of the free convective flow with time dependent boundary condition was investigated. Makinde [14] investigated the effect of radiative heat transfer on the pulsatilecouple stress fluid flow with time dependent boundary condition on the heated plate. It is well known that the no-slip condition is not realistic in some flows involving nanochannel, micro-channel and flows over coated plates with hydrophobic substances. Adesanya and Gbadeyan [15] studied the flow and heat transfer of steady non-Newtonian fluid flow noting the fluid slip in the porous channel. In perspective on this, Adesanya and Gbadeyan [16] investigated the stream and warmth of the excited non-Newtonian liquid pass, considering the fluid slip in the permeable recurrence.

2. Formulation and Solution of the Problem

Here we consider the time-dependent Couette flow of an electrically conducting and optically thin viscous incompressible fluid in a porous medium bounded by two infinite non-conducting horizontal parallel walls under the influence of an externally applied uniform magnetic field B_0 and radiative heat flux. It is assumed that the fluid has a low electrical conductivity and that the electromagnetic force generated is quite small, so that the magnetic energy (Joulean heat) dissipation and the induced magnetic field are negligible. It is further assumed that the fluid has small viscosity and low speed. Consequently the viscous energy dissipation is omitted in the energy equation. The lower wall is abruptly set in motion from rest with a velocity $\overline{U}$ that oscillates in time about a constant mean velocity U_0. Additionally, it is supposed that the temperature of the moving lower plate oscillates in time about a non-zero constant mean.

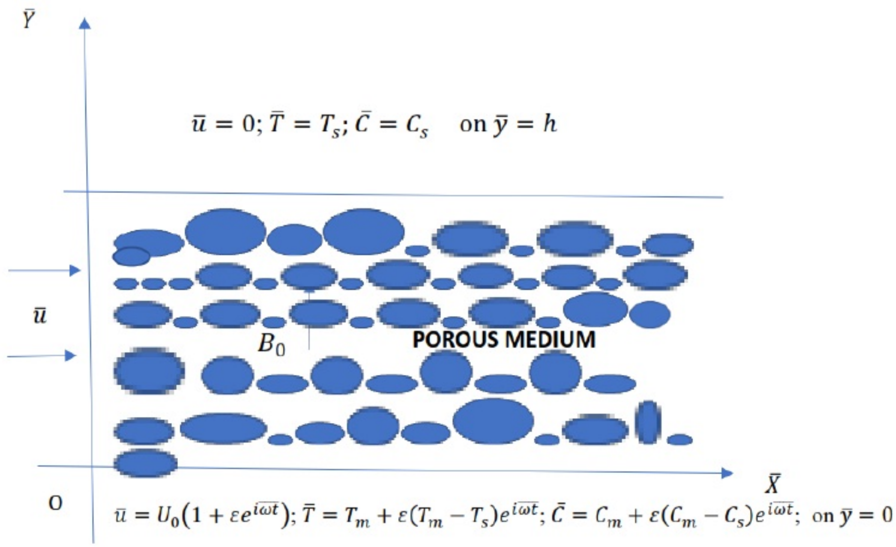

Fig. 1 Physical Configuration of the problem

For an incompressible fluid, the governing equations (with Boussinesq approximation) are

Momentum Equation :

$$\rho\frac{\partial \overline{u}}{\partial \overline{t}} = \rho\frac{\partial \overline{U}}{\partial \overline{t}} + \mu\frac{\partial^2 \overline{u}}{\partial \overline{y}^2} + \partial g\beta(\overline{T} - T_s) + \rho g\overline{\beta}(\overline{C} - C_S) - \left(\frac{\mu}{\overline{K}} + \sigma B_0^2\right)(\overline{u} - \overline{U}) \tag{1}$$

Energy Equation

$$\frac{\partial \overline{T}}{\partial \overline{t}} = \frac{\kappa}{\rho C_p}\frac{\partial^2 \overline{T}}{\partial \overline{y}^2} - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial \overline{y}}. \tag{2}$$

Species Continuity Equation :

$$\frac{\partial \overline{C}}{\partial \overline{t}} = D\frac{\partial^2 \overline{C}}{\partial \overline{y}^2} + \overline{C}_r(C_s - \overline{C}). \tag{3}$$

Subject to the boundary conditions

$\overline{u} = U_0(1 + \epsilon^{\overline{i\omega t}});$

$$\left.\overline{T} = \begin{array}{l} T_m + \epsilon(T_m - T_s)e^{\overline{i\omega t}}; \overline{C} = C_m + \epsilon(C_m - C_s)e^{\overline{i\omega t}}; om\ \overline{y} = 0 \\ \overline{u} = 0; \overline{T} = T_s; \overline{C} = C_s \quad on \quad \overline{y} = h \end{array}\right\} \tag{4}$$

It is assumed that the wall temperature T_m and T_s are sufficiently high in order to induce radiative thermal energy transfer. The fluid being optically thin with relatively low density, the approximation of Cogley et al., [11] for the radiative heat flux q_r in the energy equation [2] is taken as

$$\frac{\partial q_r}{\partial \overline{y}} = 4\alpha^2(\overline{T} - T_s). \tag{5}$$

In order to render the mathematical model normalized, the following non-dimensional quantities are introduced.

$$\left.\begin{array}{l} y = \frac{\overline{y}}{h}, u = \frac{\overline{u}}{U_0}, U = \frac{\overline{U}}{U_0}, t = \overline{\omega t}, \omega = \frac{\overline{\omega} h^2}{v}, \chi^2 = \frac{h^2}{K}, Pr = \frac{v}{\overline{\alpha}}, \overline{\alpha} = \frac{\kappa}{\rho C_p}, Cr = \frac{h\overline{C}r}{U_0}, \\ M^2 = \frac{\sigma B_0^2 h^2}{\rho v}, N^2 = \frac{4\alpha^2 h^2}{\kappa}, Sc = \frac{v}{D}, Re = \frac{U_0 h}{v}, U(t) = 1 + \epsilon e^{it}, \\ \theta = \frac{(\overline{T} - T_s)}{(T_m - T_s)}, \phi = \frac{(\overline{C} - C_s)}{(C_m - C_s)}, Gr = \frac{g\beta h^2 (T_m - T_s)}{vU_0}, Gm = \frac{g\overline{\beta} h^2 (C_m - C_s)}{vU_0} \end{array}\right\} \tag{6}$$

All the physical quantities are mentioned in the nomenclature.

The governing equations in non-dimensional form are as follows

$$\omega \frac{\partial u}{\partial t} = \omega \frac{\partial U}{\partial t} + \frac{\partial^2 u}{\partial y^2} + Gr\theta + Gm\phi - (\chi^2 + M^2)(u - U) \tag{7}$$

$$\omega Pr \frac{\partial \theta}{\partial t} = \frac{\partial^2 \theta}{\partial y^2} - N^2 \theta \tag{8}$$

$$\omega Sc \frac{\partial \phi}{\partial t} = \frac{\partial^2 \phi}{\partial y^2} - ReScCr\phi. \tag{9}$$

The relevant boundary conditions in non-dimensional form are

$$u = \left.\begin{array}{c} 1 - \epsilon e^{it}, \theta = 1 + \epsilon e^{it}, \phi = 1 + \epsilon e^{it} \quad at \quad y = 0 \\ u = 0, \theta = 0, \phi = 0 \quad at \quad y = 1 \end{array}\right\} \tag{10}$$

Method of Solution :

To solve the equatiob (7), (8) and (9) subject to the boundary condition (10), we take

$$\left.\begin{array}{l} u(y,t) = u_0(y) + \epsilon u_1(y) e^{it} + 0(\epsilon^2) \\ \theta(y,t) = \theta_0(y) + \epsilon \theta_1(y) e^{it} + 0(\epsilon^2) \\ \phi(y,t) = \phi_0(y) + \epsilon \phi_1(y) e^{it} + 0(\epsilon^2) \end{array}\right\} \tag{11}$$

Substituting the transformations () into (), (),() and neglecting the coefficients of $0(\epsilon^2$, we derive the following set of differential equations.

$$\frac{d^2 u_0}{dy^2} - (\chi^2 + M^2) u_0 = -(\chi^2 + M^2) - Gr\theta_0 + Gm\phi_0 \tag{12}$$

$$\frac{d^2\theta_0}{dy^2} - N^2\theta_0 = 0 \tag{13}$$

$$\frac{d^2\phi_0}{dy^2} - ReScCr\phi_0 = 0 \tag{14}$$

$$\frac{d^2u_1}{dy^2} - (\chi^2 + M^2 + i\omega)u_1 = -(\chi^2 + M^2 + i\omega) - Gr\theta_1 + Gm\phi_1 \tag{15}$$

$$\frac{d^2\theta_1}{dy^2} - (N^2 + i\omega Pr)\theta_1 = 0 \tag{16}$$

$$\frac{d^2\phi_1}{dy^2} - (ReCr + i\omega)Sc\phi_1 = 0. \tag{17}$$

Subject to the following boundary conditions:

$$\left.\begin{array}{l} u_0 = 1, \theta_0 = 1, \phi_0 = 1 \quad at \quad y = 0 \\ u_0 = 0, \theta_0 = 0, \phi_0 = 0 \quad at \quad y = 1 \\ u_1 = 1, \theta_1 = 1, \phi_1 = 1 \quad at \quad y = 0 \end{array}\right\} \tag{18}$$

The equations (12) to (17) are solved subject to the boundary conditions (18) and the solutions are as follows:

$$u_0(y) = C_4e^{\lambda y} + C_5e^{-\lambda y} + 1 - \frac{GrC_1}{(N^2 - \lambda^2)}(e^{Ny} - e^{-N(y-2)}) - \frac{GmC_8}{(L^2 - \lambda^2)}(e^{Ly} - e^{-L(y-2)}) \tag{19}$$

$$\theta_0(y) = C_1(e^{Ny} - e^{-N(y-2)}) \tag{20}$$

$$\phi_0(y) = C_8(e^{Ly} - e^{-L(y-2)}) \tag{21}$$

$$u_1(y) = C_6e^{\Lambda y} + C_7e^{-\Lambda y} + 1 - \frac{GrC_3}{(\delta^2 - \Lambda^2)}(e^{\delta y} - e^{-\delta(y-2)}) - \frac{GmC_{10}}{(\eta^2 - \Lambda^2)}(e^{ny} - e^{-\eta(y-2)}) \tag{22}$$

$$\theta_1(y) = C_3(e^{\delta y} - e^{-\delta(y-2)}) \tag{23}$$

$$\phi_1(y) = C_{10}(e^{\eta y} - e^{-\eta(y-2)}). \tag{24}$$

The expressions for the velocity, temperature and concentration field respectively are given by

$$u(y,t) = \left.\begin{array}{l} C_4e^{\lambda y} + C_5e^{-\lambda y} + 1 - \frac{GrC_1}{(N^2-\lambda^2)}(e^{Ny} - e^{-N(y-2)}) - \frac{GmC_8}{(L^2-\lambda^2)}(e^{Ly} - e^{-L(y-2)}) \\ +\epsilon(u_1(y) = C_6e^{\Lambda y} + C_7e^{-\Lambda y} + 1 - \frac{GrC_3}{(\delta^2-\Lambda^2)})(e^{\delta y} - e^{-\delta(y-2)}) \\ -\frac{GmC_{10}}{(\eta^2-\Lambda^2)}(e^{\eta y} - e^{-\eta(y-2)}) \end{array}\right\} \tag{25}$$

$$\theta(y,t) = C_1(e^{Ny} - e^{-N(y-2)}) + \epsilon(C_3(e^{\delta y} - e^{-\delta(y-2)})) \tag{26}$$

$$\phi(y,t) = C_8(e^{Ly} - e^{-L(y-2)}) + \epsilon(C_{10}(e^{\eta y} - e^{-\eta(y-2)})) \tag{27}$$

where the constants $C_1, C_3, C_4, C_5, C_6, C_7, C_8, C_{10}, \delta, \lambda, \Lambda, L, \eta$ are defined in the Appendix.

Skin Friction

The non-dimensional skin frictions τ_0 and τ_1 on the walls at $y = 0$ and $y = 1$ are specify by

$$\begin{aligned} \tau_0 &= -\left[\frac{\partial u}{\partial y}\right]_{y=0} \\ &= -\left[\begin{array}{l} \lambda(C_4 - C_5) - \frac{GrNC_1}{(N^2-\lambda^2)}(1+e^{2N}) - \frac{GmLC_8}{(L^2-\lambda^2)}(1+e^{2L}) \\ \\ +\epsilon\left\{\Lambda(C_6 - C_7) - \frac{Gr\delta C_3}{(\delta^2-\Lambda^2)}(1+e^{2\delta}) - \frac{Gm\eta C_{10}}{(\eta^2-\Lambda^2)}(1+e^{2\eta})\right\} e^{it} \end{array}\right] \end{aligned} \tag{28}$$

and

$$\begin{aligned} \tau_1 &= -\left[\frac{\partial u}{\partial y}\right]_{y=1} \\ &= -\left[\begin{array}{l} \lambda(C_4e^{\lambda} - C_5e^{-\lambda}) - \frac{2GrNC_1}{(N^2-\lambda^2)}e^N - \frac{2GmLC_8}{(L^2-\lambda^2)}e^L \\ \\ +\epsilon\left\{\Lambda(C_6e^{\Lambda} - C_7^{-\Lambda}) - \frac{2Gr\delta C_3}{(\delta^2-\Lambda^2)} - \frac{2Gm\eta C_{10}}{(\eta^2-\Lambda^2)}e^{\eta}\right\} e^{it} \end{array}\right] \end{aligned} \tag{29}$$

Nusselt Number

The coefficient of the rate of heat transfer on the walls $y = 0$ and $y = 1$ in terms of the Nusselt number are given by

$$Nu_0 = -\left[\frac{\partial \theta}{\partial y}\right]_{y-0} = -\{NC_1(1+e^{2N}) + \epsilon\delta C_3(1+e^{2\delta})e^{it}\} \tag{30}$$

and

$$Nu_1 = -\left[\frac{\partial \theta}{\partial y}\right]_{y=1} = -\{2NC_1e^N + 2\epsilon\delta C_3e^{\delta}e^{it}\}. \tag{31}$$

Rate of Mass Transfer :

The co-efficient of the rate of mass transfer on the walls at $y = 0$ and $y = 1$ to the fluid in terms of Sherwood number described as

$$Sh_0 = -\left[\frac{\partial \phi}{\partial y}\right]_{y=0} = -\{LC_8(1+e^{2L}) + \epsilon\eta C_{10}(1+e^{2\eta})e^{it}\} \tag{32}$$

and

$$Sh_1 = -\left[\frac{\partial\phi}{\partial y}\right]_{y=1} = -\{2LC_8e^L + 2\epsilon\eta C_{10}e^{\eta}e^{it}\}. \tag{33}$$

3. Results and Discussion

Here we investigated the effects of the parameters namely Grashoff number (Gr), Solutal Grashof number (Gm), Schmidt number (Sc), Chemical reaction (Cr) and radiation parameter (N) on the flow and transport characteristics presented in our work. We assume some fixed values for the parameters as $t = \frac{\pi}{2}, Pr == .71, Re = 1, \chi = 1, \epsilon = 0.02$, which is valued for air at 20^0C at one atmospheric pressure.

The figures 2 to 5 depict the nature of the main flow field u versus the channel width y, under the influence of Gr, Gm, Sc and Cr. It is seen that the flow is accelerated for increasing values of Gr and Gm whereas a rise in each of Sc and Cr impedes the flow. It is clear that a rise in Gr and Gm indicates a corresponding growth in the temperature and concentration gradients respectively and consequently an increase in the buoyancy forces. This boosts the main flow field for this buoyancy driven flow. Further, an increase in Sc signifies a fall in mass diffusivity D, which in turn denotes a drop in the concentration buoyancy force. This decelerates the main flow. Moreover an increase in Cr denotes greater consumption of chemical species or a fall in the mean flow speed U_0. This subsequently leads to a fall in the concentration buoyancy forces or a fall in the mean velocity. Accordingly, the main flow decelerates.

Figures 6 and 7 show that an increase in each of N and Sc leads to a fall in the temperature (θ) and concentration (ϕ). Hence, an augmentation in radiative heat absorption from the fluid medium causes a drop in its temperature. The concentration drops off on account of a fall in mass diffusivity. From Figures 8 and 9, one can observe a growth in the magnitudes of shear stress at the walls, for increasing mass-buoyancy effects is inhabited.

From Figures 10 and 11 we see that a growth in Sc (i.e. fall in mass diffusivity) amplifies the magnitude of τ_0 (shear stress at the moving wall) and causes a decay in the magnitude of τ_1 (shear stress at the stationary wall).

We observe from figures 12 and 13 that a growth in N (i.e. increase in radiative heat absorption) enhances heat transfer at the moving wall but diminishes heat transfer at

the stationary wall.
The figures 14 and 15 indicate a decline in the mass flux at the walls on account of increasing consumption of chemical species (i.e. due to rising of Cr). Further it is inferred from the figures 6to 9that a growth in the magnetic field parameter M causes decay in the magnitude of τ_0 (shear stress at the moving wall) and boosts the magnitude of τ_1(shear stress at the stationary wall).
Figures 12 to 13 depict a nearly steady influence of ω (dimensionless frequency parameter) on the rates of heat and mass transfer at the walls. Hence the heat and mass fluxes are not significantly affected by ω.

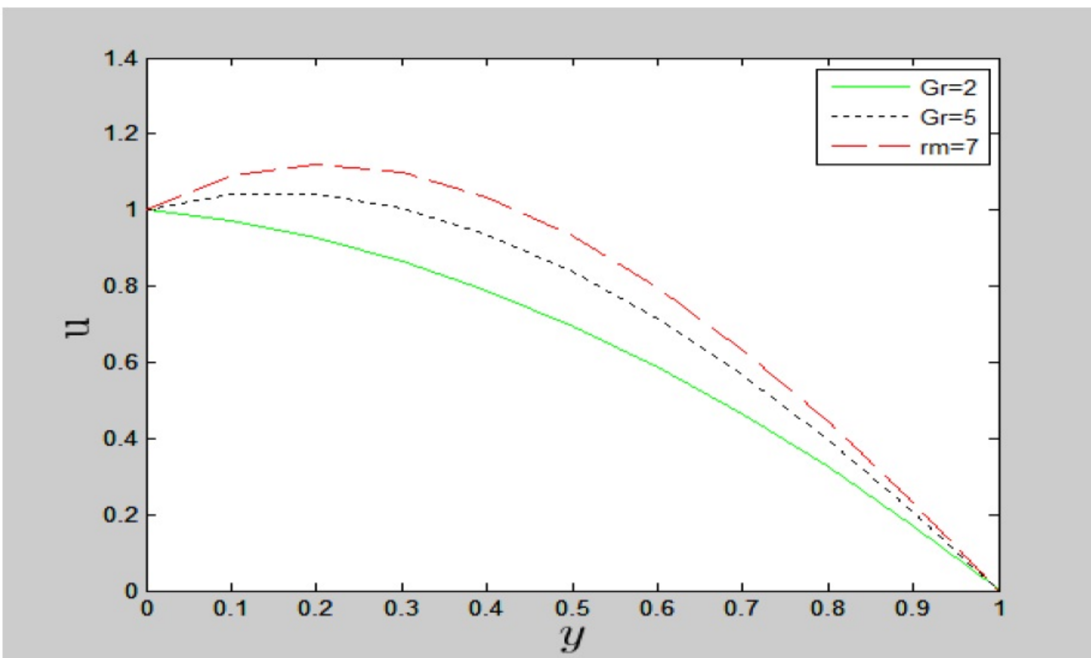

Figure 2 : Velocity u against y, under Gr for
$Pr = 0.71, Sc = 0.2, Re = 1, N = 1, Gm = 0, Cr = 1, \omega = 5, M = 1, t = 1.57, \epsilon = 0.02$

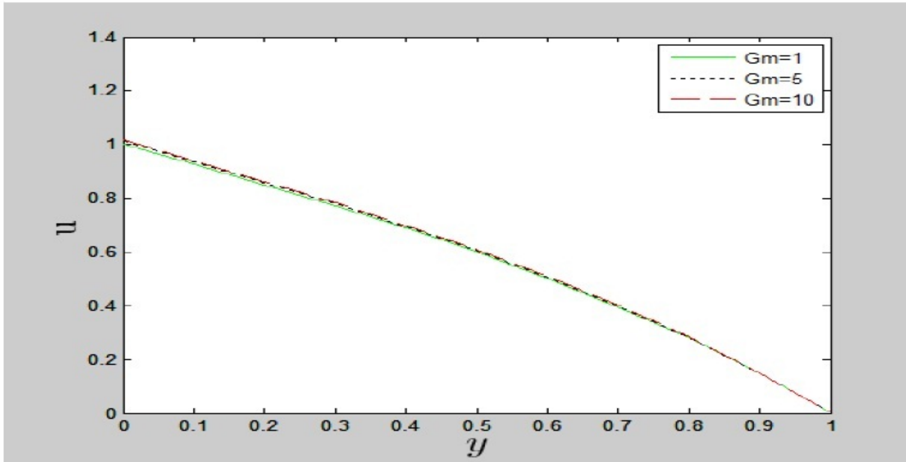

Figure 3 : Velocity u against y, under Gm for
$Pr = 0.71, Sc = 0.2, Re = 1, N = 1, Gr = 1, Cr = 1, \omega = 5, M = 1, t = 1.57, \epsilon = 0.02$

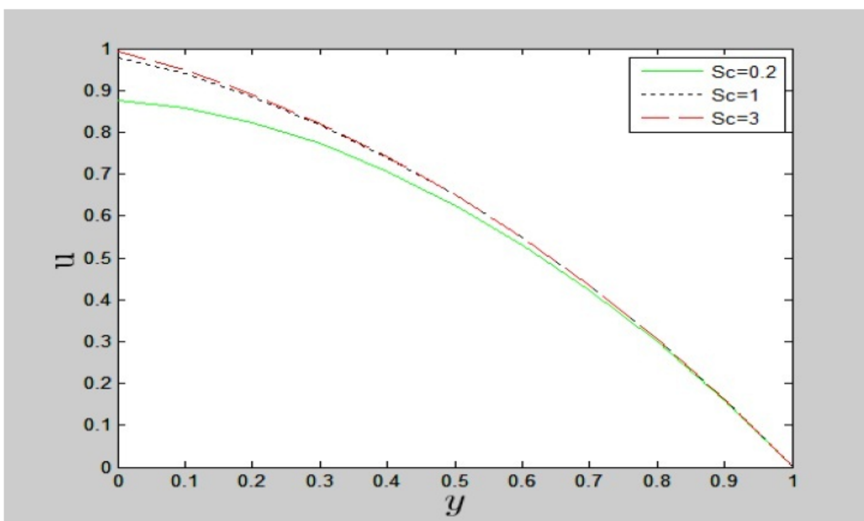

Figure 4 : Velocity u against y, under Sc for
$Pr = 0.71, Gm = 1, Re = 1, N = 1, Gr = 1, Cr = 1, \omega = 5, M = 1, t = 1.57, \epsilon = 0.02$

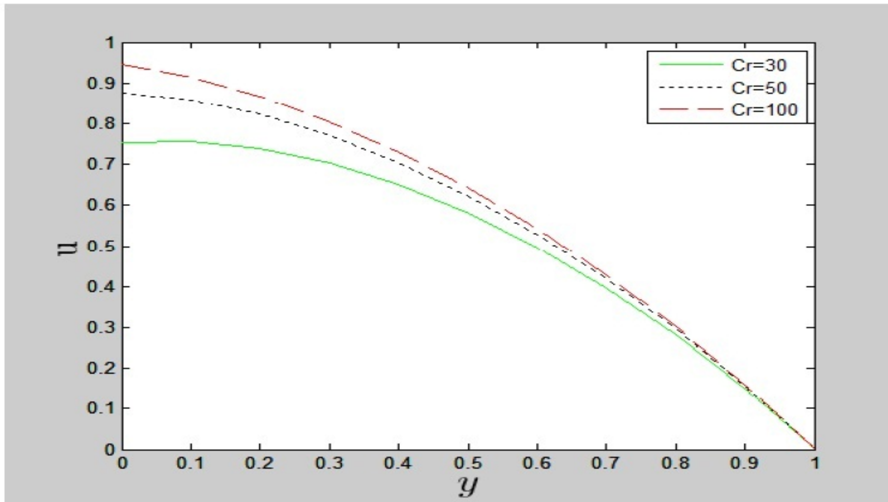

Figure 5 : Velocity u against y, under Cr for
$Pr = 0.71, Gm = 1, Re = 1, N = 1, Gr = 1, Sc = 0.2, \omega = 5, M = 1, t = 1.57, \epsilon = 0.02$

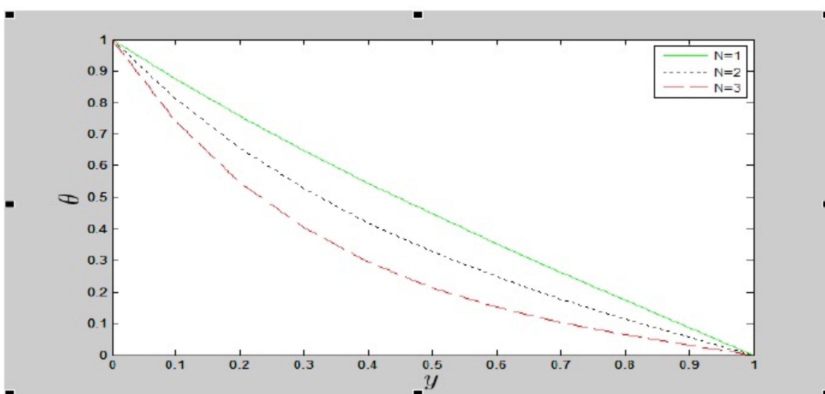

Figure 6 : Temperature field θ against y, under N for $Pr = 0.71, Gm = 1, Re = 1, N = 1, Cr = 1, \epsilon = 0.02, Gr = 1, Sc = 0.2, \omega = 5, M = 1, t = 1.57$

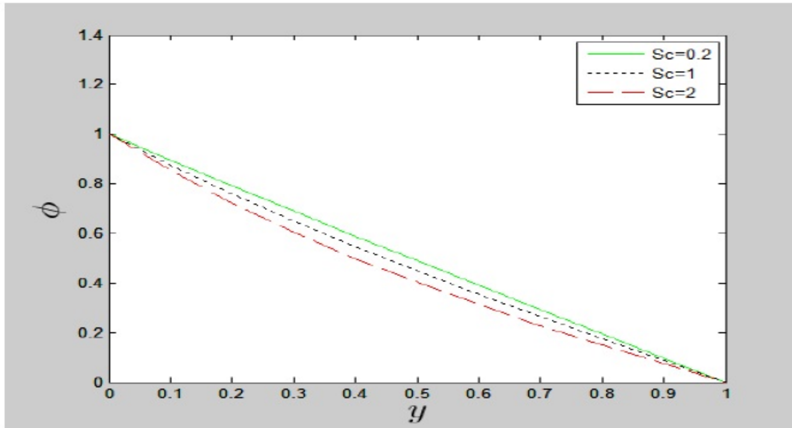

Figure 7 : Concentration field ϕ against y, under Sc for $Pr = 0.71, Gm = 0.2, Re = 1, N = 1, Cr = 1, Cr = 1, \epsilon = 0.02, Gr = 1, \omega = 5, M = 1, t = 1.57$

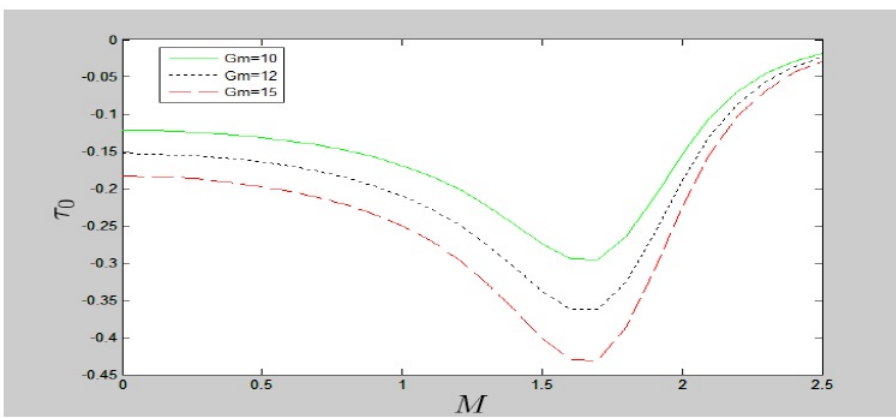

Figure 8 : Skin friction τ_0 against M, under Gm for
$Pr = 0.71, Re = 1, N = 1, Cr = 1, \epsilon = 0.02, Gr = 1, Sc = 0.2, \omega = 5, t = 1.57$

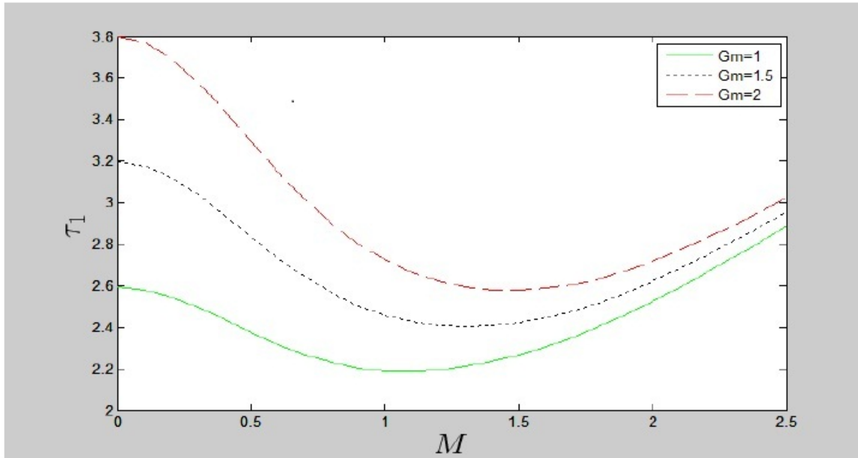

Figure 9 : Skin friction τ_1 against M, under Gm for $Pr = 0.71, Re = 1, N = 1, Cr = 1, \epsilon = 0.02, Cr = 1, \epsilon = 0.2, Gr = 1, Sc = 0.2, \omega = 5, t = 1.57$.

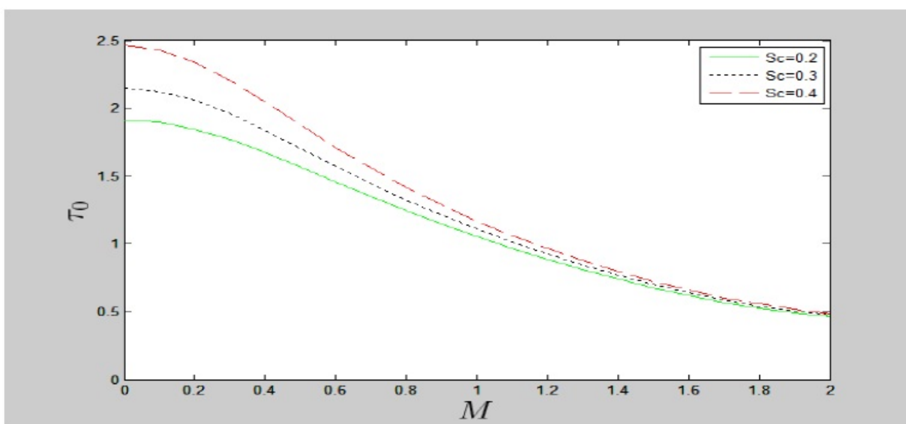

Figure 10 : Skin friction τ_0 against M, under Sc for
$Pr = 0.71, Re = 1, N = 1, Cr = 1, \epsilon = 0.02, Gr = 1, Gm = 1, \omega = 5, t = 1.57$

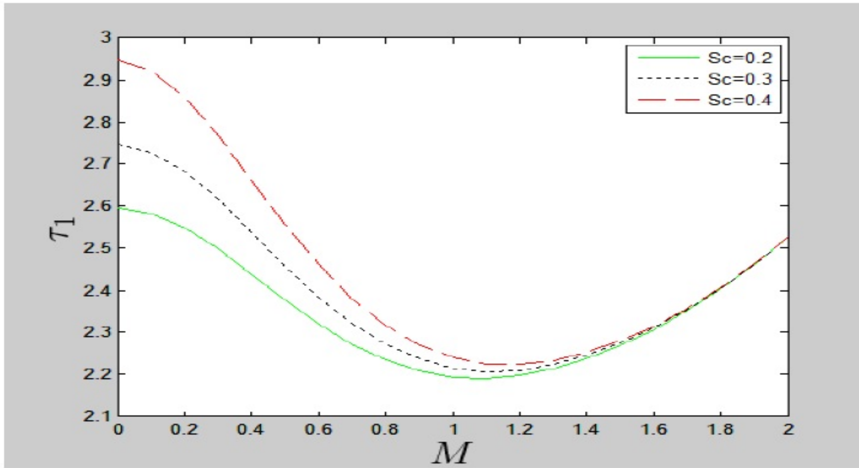

Figure 11 : Skin friction τ_1 against M, under Sc for
$Pr = 0.71, Re = 1, N = 1, Cr = 1, \epsilon = 0.02, Gr = 1, Gm = 1, \omega = 5, t = 1.57$

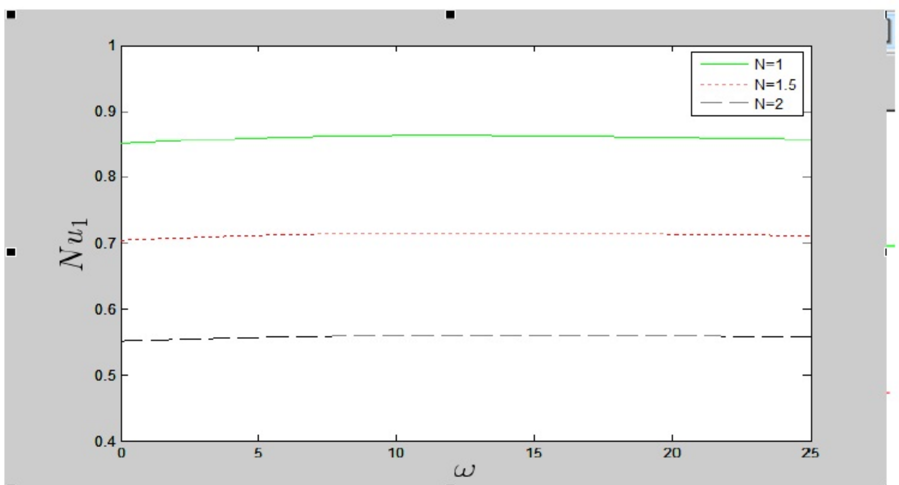

Figure 12 : Nusselt number Nu_0 against ω, under Sc for
$Pr = 0.71, Re = 1, N = 1, Cr = 1, M = 1, Gr = 1, Gm = 1, \epsilon = 0.02, t = 1.57.$

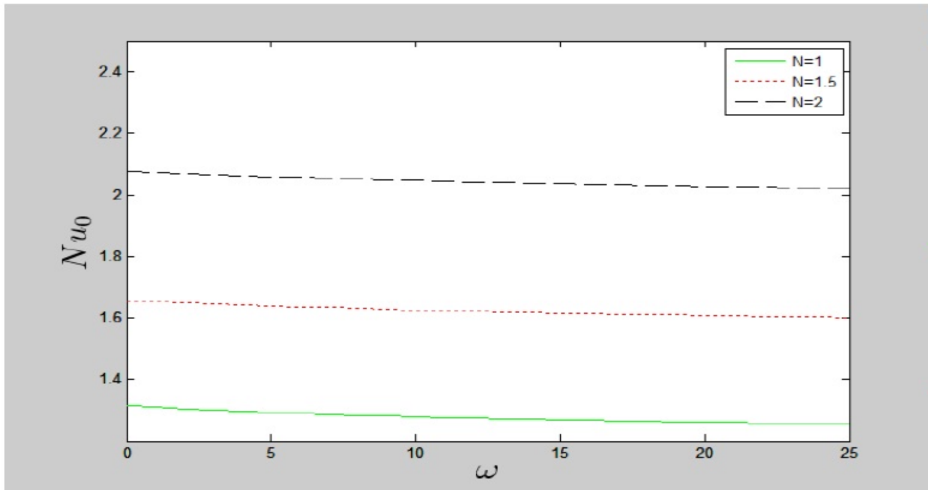

Figure 13 : Nusselt number Nu_1 against ω, under Sc for
$Pr = 0.71, Re = 1, N = 1, Cr = 1, M = 1, Gr = 1, Gm = 1, \epsilon = 0.02, t = 1.57$

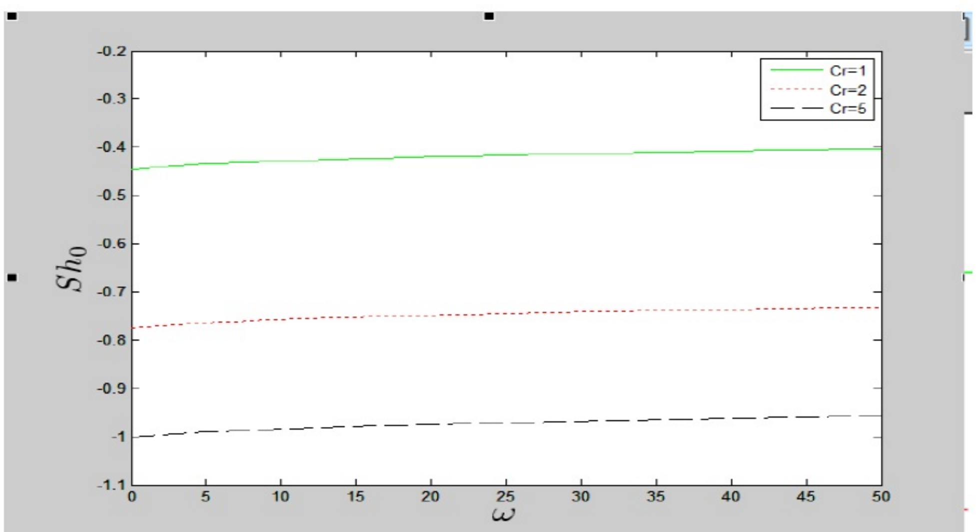

Figure 14: Sherwood number Sh_0 against ω, under Cr for
$Pr = 0.71, Re = 1, N = 1, Cr = 1, M = 1, Gr = 1, Gm = 1, \epsilon = 0.02, t = 1.57$

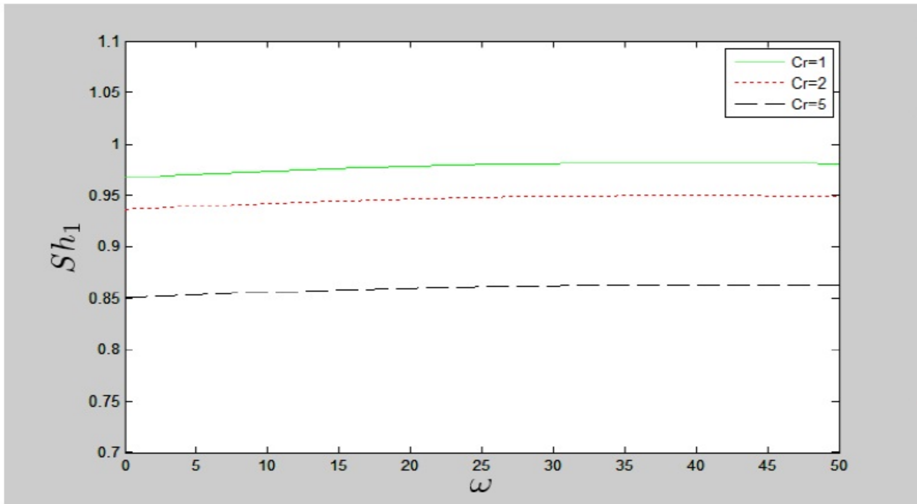

Figure 15 : Nusselt number sh_1 against ϵ, under Cr for
$Pr = 0.71, Re = 1, N = 1, Cr = 1, M = 1, Gr = 1, Gm = 1, \omega = 5, t = 1.57$

4. Conclusion

Based on the results and discussion section, the following conclusions are drawn:

- A growth in the buoyancy forces induced by temperature and concentration gradients leads to acceleration of the main flow.
- A drop in chemical mass diffusivity causes retardation in the main flow. Also, the flow decelerates on account of increased consumption of chemical species or due to fall in the mean velocity of the moving wall.
- An augmentation in the radiative heat absorption from the fluid lowers its temperature. Moreover, the concentration falls due to a drop in mass diffusivity.
- The wall shear stresses increase in their magnitudes on account of growth in mass-buoyancy effects i.e. due to growth in Solutal Grashof number.
- A decline in mass diffusivity increases the magnitude of shear stress at the moving wall and reduces the magnitude of shear stress at the fixed wall.
- The heat flux at the moving wall is enhanced whereas that at the stationary wall is diminished on account of growth in radiative heat absorption.

- The heat and mass transfer rates at the walls are not significantly influenced by the frequency of oscillation.
- An escalation in the consumption of species (due to chemical reaction) leads to decay in the rates of mass transfer at the walls.
- The imposition of the magnetic field causes decay in the magnitude of shear stress at the moving wall. However, the shear stress at the stationary wall escalates in magnitude, due to a growth in the magnetic field strength.

Appendix

$C_1 = \frac{1}{(1-e^{2N})}$
$C_3 = \frac{1}{(1-e^{2\delta})}$
$C_4 = \frac{1}{(N^2-\lambda^2)(1-e^{2N})}\{Gr + e^{\lambda}(N^2 - \lambda^2)\}$
$C_5 = \frac{Gr}{(N^2-\lambda^2)} - C_4$
$C_6 = \frac{1}{(\delta^2-\Lambda^2)(1-e^{2\Lambda})}\{Gm + e^{\Lambda}(\delta^2 - \Lambda^2)\}$
$C_7 = \frac{Gm}{(\delta^2-\Lambda^2)} - C_6$
$C_8 = \frac{1}{(1-e^{2L})}$
$C_{10} = \frac{1}{(1-e^{2\eta})}$
$\delta = \sqrt{(N^2 + i\omega Pr)}$
$\lambda = \sqrt{(\chi^2 + M^2)}$
$\Lambda = \sqrt{(\lambda^2 + i\omega)}$
$L = \sqrt{ReScCr}$
$\eta = \sqrt{(ReCr + i\omega)Sc}$

NOMENCLATURE

- h Distance between two plates B_0 Electromagnetic induction
- C Concentration C_m Concentration at $y = 0$ C_s Concentration at $y = 1$
- Cr Rate of first order homogeneous chemical reaction
- Cr Non-dimensional chemical reaction parameter

- Cp Specific heat at constant pressure
- D Mass diffusion coefficient
- g Gravitational acceleration;
- Gm Solutal Grashof number
- Gr Grashof number
- $\overline{K}$ Permeability of the medium
- K Permeability parameter
- M Hartmann number
- N Thermal Radiation parameter
- Pr Prandtl number
- q_r The radiative heat flux
- Re Reynolds number
- Sc Schmidt number $\bar{t}$ The time
- t Non-dimensional time
- T Fluid temperature
- T Dimensionless fluid temperature
- T_m Temperature at $y = 0$
- T_s Temperature at $y = 1$
- $\overline{u}$ The velocity
- u Dimensionless velocity
- $\overline{U}$ Free steam velocity
- U_0 Mean constant free steam velocity

- (x, y) Coordinate system
- $(\overline{x}, ovy)$ Non-dimensional co-ordinate system.

Greek symbols :

α . Mean radiation absorption coefficient
β Coefficient of volume expansion for heat transfer
$\overline{\beta}$ Co-efficient of volume expansion for mass transfer
ν Kinematic viscosity
μ Coefficient of viscosity
σ Electrical conductivity
ρ Fluid density
$\overline{\varpi}$ Dimensional frequency parameter
ω Frequency parameter
χ The porosity parameter
ϵ Small reference parameter
κ Thermal conductivity
θ Non-dimensional temperature
ϕ Non-dimensional concentration

References

[1] Neild D. A., Bejan A., Convection in Porous Media, Springer, New York, NY, USA, (2006).

[2] Inghamand D. B., Pop I., Transport Phenomena in Porous Media, Elsevier, Oxford, United Kingdom, (2005).

[3] Palani G., Srikanth U., MHD flow past a semi-infinite vertical plate with mass transfer, Nonlinear Anal. Model Control 14(3) (2009), 345-356.

[4] Makinde O. D., On MHD heat and mass transfer over a moving vertical plate with a convective surface boundary condition, Canadian J. Chem. Engg., 88(6) (2010), 983-990.

[5] Narayana PVS. Effects of variable permeability and radiation absorption on MHD mixed convective flow in a vertical wavy channel with travelling thermal waves. Propul Power Res. 4(3) (2015), 150-60. doi: https://doi.org/10.1016/ j.jppr.2015.07.002.

[6] Elbashbeshy EMA, Emam TG, Abdelgaber KM. Effects of thermal radiation and magnetic field on unsteady mixed convection flow and heat transfer over an exponentially stretching surface with suction in the presence of internal heat generation/absorption. J Egyptian Math Soc 2012;20:215.22

[7] Hakeem A. K., Vishnu Ganesh N., Ganga B., Magnetic field effect on second order slip flow of Nano fluid over a stretching/shrinking sheet with thermal

radiation effect. J Magn Magn Mat 2015;381:243.57. doi: https://doi.org/10.1016/j.jmmm.2014.12.010.

[8] Baag S., Mishra S. R., Dash G. C., Acharya MR. Entropy generation analysis for viscoelastic MHD flow over a stretching sheet embedded in a porous medium. Ain Shams Eng J 2016;8(4):623.32. doi: https://doi.org/10.1016/j.asej.2015.10.017.

[9] Kalidas D. Nilangshu Acharya, Prabir Kumar Kundu, Radiative flow of MHD Jeffrey fluid past a stretching sheet with surface slip and melting heat transfer. Alex Eng J 2015;54(4):815.21. doi: https://doi.org/10.1016/j.aej.2015.06.008.

[10] Umavathi J. C., Chamkha A. J. and Mateenand A., Al-Mudhat in a horizontal composite porous medium channel. Non-Linear Anal. Model. Contr., (2009), 14, 397-415.

[11] Jha B. K. and Ajibade A. O., Free convective flow between vertical porous plates with periodic heat input. Z. Angew. Math. Mech., (2010) 90, 185-193.

[12] Jha B. K. and Ajibade A. O., Free convective flow of heat generating/absorbing fluid between vertical porous plates with periodic heat input. Int. Commun. Heat Mass Transfer, 36 (2009), 624-631.

[13] Jha B. K. and Ajibade A. O., Effect of viscous dissipation on natural convection flow between vertical parallel plates with time periodic boundary conditions. Commun. Nonlinear Sci. Numer. Simul., 17 (2012), 1576-1587.

[14] Adesanya S. O. and Makinde O. D., Heat transfer to magnetohydrodynamic non-Newtonian couple stress pulsatile flow between two parallel porous plates. Z. Naturforsch., 67a (2012), 647-656.

[15] Adesanya O. and Gbadeyan J. A., A domian decomposition approach to steady visco-elastic fluid flow with slip through a planar channel. Int. J. Nonlinear Sci., 9 (2010), 86- 94.

[16] Adesanya S. O., Oluwadare E. O., Falade J. A. and Makinde O. D., Hydromagnetic natural convection flow between vertical parallel plates with time-periodic boundary conditions. Journal of Magnetism and Magnetic Materials, 396 (2015), 295-303.