Nigerian Journal of Mathematics and Applications
Volume **26**, (2017), 45 − 60. *Printed by Unilorin press*
©*Nig. J. Math. Appl.* *http://www.njmaman.com*

Hydromagnetic radiative flow past a vertical oscillating plate with chemical reaction in presence of heat source

P. F. Fasogbon* and Y. O. Tijani

Abstract

In the present article, we study time-varying hydromagnetic chemically reacting free convective flow of a viscous, incompressible radiating fluid past an infinite oscillating vertical plate with variable surface conditions subject to transverse magnetic field in the presence of temperature dependent heat source. Soret and Dufour effects are taken into consideration. The radiative heat flux is simplified by using Rosseland approximation. The dimensionless governing equations are solved using the symbolic algebra software MAPLE 17. The velocity, temperature and concentration profiles are presented in graphs and discussed. It is observed that Soret, Dufour, chemical reaction parameter, heat source parameter, radiation parameter and magnetic field parameter affect the flow pattern significantly.

Received: 22/08/2016, Accepted: 15/01/2017, Revised: 05/02/2017.
2015 *Mathematics Subject Classification.* 86A30 & 86A25. * Corresponding author.
Key words and phrases. Temperature-dependent heat source; Chemical Reaction; Oscillating vertical plate; Theta method scheme on MAPLE 17
Department of Mathematics, Obafemi Awolowo University, Ile-Ife, 220005, Nigeria
E-mail: pfasogbon@yahoo.com*, olodyusuf@gmail.com

Nomenclature

$\vec{B}$	magnetic induction vector
B_o	uniform transverse magnetic field
C	dimensionless species concentration
C_f	dimensionless Skin friction
C'	species concentration
C'_∞	ambient concentration
C'_w	concentration at the plate
C_p	specific heat at constant pressure
C_s	concentration susceptibility
$\vec{D} = \varepsilon\vec{E}$	current displacement
D_m	mass diffusion coefficient
$\vec{E}$	applied electric field
F	Dufour number
G_m	mass Grashof number
G_r	thermal Grashof number
$\vec{J}$	the electric current density
K'_r	Chemical reaction parameter
K_r	dimensionless chemical reaction parameter
K_T	thermal diffusion ratio
M	magnetic field parameter
N	radiation parameter
P_r	Prandtl number
Q_o	volumetric heat source parameter
q_r	radiative heat flux
S_c	Schmidt number
S_r	Soret number
T	temperature of the fluid
T_w	temperature of the plate
T_∞	ambient temperature
t'	time
t	dimensionless time
u	dimensionless velocity
u'	velocity of the fluid in x'-direction
u_o	velocity of the plate
(x', y')	dimensional coordinate system
$(x,\ y)$	flow dimensional coordinate
β_T	coefficient of thermal expansion
β_m	coefficient of solutal expansion
δ	heat source parameter
κ	thermal conductivity
μ	dynamic viscosity
ν	kinematic viscosity $(m^2\ s^{-1})$
ρ	density of the fluid
σ	electrical conductivity
θ	non-dimensional temperature
wt	phase angle

1. Introduction

Hydromagnetic free convective flow has a number of applications in science, technology, industries and engineering areas. For instance, nuclear power plant, propulsion devices for aircraft, missiles, satellites and other space vehicles; where radiative heat transfer is of paramount importance. Other examples include, hydromagnetic power generation system, geophysics, cooling of nuclear reactors, heat exchanger design and so on.

Free convection by buoyancy mechanisms arising from both thermal and species diffusion has been studied extensively in the past and various extensions of the problem have been reported in the literature. Ram [1] presented an account of several investigations of heat and mass transfer carried out by several authors in the field of hydromagnetic. Chamkha and Khaled [2], Chen [3], Alam et al. [4], Rani et al. [5], Kristaiah et al. [6], Hemamalini and Sureshkumar [7] and many others have worked in this area of interest.

Accordingly, Raptis and Massalas [8] have studied the effects of radiation on the oscillatory flow past a plate when the fluid is incompressible, viscous and electrically conducting. Raptis et al. [9] analysed the hydromagnetic free convection flow of an optically thin gray gas past a stationary vertical infinite plate in the presence of radiation, when the induced magnetic field is taken into account.

Simultaneous diffusion of thermal energy and of chemical species problems with chemical reaction is of immense practical importance for scientists and engineers due to its almost universal occurrence in many branches of science and engineering. This type of flow found application in power industry and chemical process industries. The theoretical study of chemical reaction effect on vertical oscillating plate with variable surface conditions was carried out by Muthucumaraswamy and Meenakshisundaram [10]. Later, Muthucumaraswamy and Janakiraman [11] extended this idea on isothermal vertical oscillating plate. An analysis on aligned magnetic field and chemical reaction effects on flow through porous medium; past a vertical oscillating plate and over a semi infinite porous plate, was carried out respectively, by Sandeep and Sugunamma [12], and Sugunamma et al. [13]. Kishore et al. [14], and Sasikumar and Govindarajan [15] studied the chemical reaction effect on MHD free convection flow of fluid past an exponentially accelerated vertical plate and parallel plates, respectively. Chemical reaction effects on unsteady MHD flow past an impulsively started oscillating inclined plate with variable surface conditions in the presence of Hall current was studied by Rajput and Kumar [16].

Many challenging flow problems have been studied in time-varying radiative hydromagnetic convection flows with variable surface conditions by Rajesh and Verma [17] and Kishore et al. [18a,b]. Literature reveals that transient free convection plays an important role in many industrial and environmental situations such as air-conditioning systems, atmospheric flows, motors, thermal regulation

process, cooling of electronic devices, and security of energy systems. The study of heat source or sink effects in moving fluid finds applications in several physical problems such as fluids undergoing exothermic or endothermic chemical reaction. The use of magnetic field influence the heat source or sink process in electrically conducting fluid flows. Furthermore, in numerous industrial applications of time-varying free convection flow problems, there exists a heat source or a sink which is either a constant or temperature gradient or temperature-dependent heat sources in the form of a coil or a battery (Reddy and Rao [19]).
All the above mentioned studies; based on the combined buoyancy effects arising from the simultaneous diffusion of thermal energy and of chemical species, from different geometries, are coupled through the buoyancy terms alone. There is no such possibility in the case of fluid with high species concentration level, thus necessitate the inclusion of Soret and Dufour effects. These influences are studied as second order phenomena and had applications in many areas such as petrology, geosciences, hydrology, and so on.
When heat transfer is associated with mass transfer in a moving fluid, it can be found that an energy flux is generated not only by temperature gradients, but also by concentration gradients. Soret effects refers to mass flux produced by a temperature gradient and the Dufour effect refers to heat flux produced by a concentration gradient. In recent past, studies have been carried out considering the Soret and Dufour effects by El-Arabawy [20], Reddy and Rao [19], Sreenivasulu and Reddy [21] and Ojjela and Kumar [22] in different geometries for different surface/wall/sheet temperature and concentration conditions. Another important paper is that of Sulochana and Tayappa [23]. They have investigated the Lie-group analysis of Soret, Dufour and chemical reaction effects on convective heat and mass transfer of an incompressible, electrically conducting fluid over a stretching sheet in the presence of heat generating sources.
The preceding literature survey shows that Soret and Dufour effects are important for intermediate molecular weight gases (H_2, air) in coupled heat and mass transfer in chemical process systems. Yet, to the best of our knowledge, Soret and Dufour effects on transient hydromagnetic free convection flow of a chemically reacting radiating fluid past an infinite oscillating vertical plate with variable surface conditions in the presence of heat source has not being investigated and the present analysis confirms the issue using the symbolic algebra software Maple 17 (Theta Method Scheme).

2. Mathematical Formulation

The transient and laminar two-dimensional flow of a viscous incompressible radiating and electrically conducting fluid, undergoing a first-order chemical reaction, past an infinite vertical oscillating plate with variable temperature and mass diffusion is considered. Here, the $x'-$ axis is taken along the plate in the vertically upward direction and the $y'-$ axis is orthogonal to the plate. Initially, the plate and the fluid are of the same temperature T_∞ with concentration level C'_∞ at all points. At time $t' > 0$, the plate starts oscillating in its own plane with a velocity $u_o cos\omega' t'$, frequency ω', the plate temperature is raised to T_w and the concentration level at the plate is raised to C'_w. The temperature of the plate is raised linearly with respect to t' and the concentration level is also raised to t'. The plate is assumed to be electrically non-conducting. The fluid properties are assumed to be constant, except the density in the buoyancy force term. The volumetric heat source/sink term in the energy equation is directly proportional to temperature differences.

It is also assumed that the effect of viscous and magnetic dissipation in the energy equation are negligible and there is a first-order homogeneous chemical reaction between the fluid and the diffusion species. A magnetic field of a uniform strength B_o is applied in the y'-direction against to the gravitational field. There is no applied electric field and the magnetic Reynolds number is much less than unity so that the induced magnetic field, Hall and ion slip current effects are negligible. Maxwell currents displacement and free charges are neglected.

The basic equations of hydromagnetic and conventional fluid dynamics of momentum, energy and species concentration for natural convection flow with Boussinesq's approximation are as follow:

$$\frac{\partial u'}{\partial t'} = \mu \frac{\partial^2 u'}{\partial y'^2} + \rho\beta_T(T - T_\infty) + \rho\beta_m(C' - C'_\infty) + \vec{F}_e, \tag{1}$$

where $\vec{F}_e$ is magnetic body (Lorentz)force and is obtained as:

$$\vec{F}_e = \vec{J} \times \vec{B} = \sigma(\vec{u} \times \vec{B}) \times \vec{B} = \sigma\Big((u', v', 0) \times (0, B_o, 0)\Big) \times \Big(0, B_o, 0\Big) = -\sigma B_o^2 u'$$

$$\nabla \cdot \vec{B} = 0, \quad \nabla \times \vec{B} = \vec{J} + \frac{\partial \varepsilon \vec{E}}{\partial t}, \quad \nabla \cdot \vec{E} = 0, \quad \text{and,} \quad \vec{J} = \sigma \vec{u} \times \vec{B} \text{ (Ohm's Law)}$$

$$\frac{\partial T}{\partial t'} = \frac{\kappa}{\rho C_p} \frac{\partial^2 T}{\partial y'^2} - \frac{Q_o}{\rho C_p}(T - T_\infty) - \frac{1}{\rho C_p} \frac{\partial q_r}{\partial y'} + \frac{D_m K_T}{C_s C_p} \frac{\partial^2 C'}{\partial y'^2}\ , \tag{2}$$

$$\frac{\partial C'}{\partial t'} = D_m \frac{\partial^2 C'}{\partial y'^2} - K'_r(C' - C'_\infty) + \frac{D_m K_T}{T_M} \frac{\partial^2 T}{\partial y'^2}\ . \tag{3}$$

Following [10, 18b], the initial and boundary conditions are:

$$t' \leqslant 0: \quad u' = 0, \quad T = T_\infty, \quad C' = C'_\infty, \quad \forall\ y'\ ,$$

$$t' > 0: \quad u' = u_o cos\omega' t', \quad T = T_\infty + (T_w - T_\infty)\frac{u_o^2}{\nu} t', \quad C' = C'_\infty + (C'_w - C'_\infty)\frac{u_o^2}{\nu} t',$$

$$\text{at } y' = 0 \tag{4}$$

$$u' \to 0, \quad T \to T_\infty, \quad C' \to C'_\infty, \quad as\ y \to \infty\ .$$

Employing the Roseland approximation, the radiative heat flux in the $y'-$ direction is given by

$$q_r = -\frac{4\sigma_s}{k_m}\frac{\partial T^4}{\partial y'}\ . \tag{5}$$

If the temperature difference within the flow are sufficiently small, then Eq.(5) can be linearized by expanding T^4 into Taylor series about T_∞ and neglecting higher-order terms to give

$$T^4 \approx 4T_\infty^3 T - 3T_\infty^4. \tag{6}$$

where σ_s is the Stefan-Boltzmann constant and k_m is the mean absorption coefficient.

Introducing the following non-dimensional quantities:

$$u = \frac{u'}{u_o}, \quad t = \frac{t'u_o^2}{\nu}, \quad y = \frac{y'u_o}{\nu}, \quad x = \frac{x'u_o}{\nu}, \quad K_r = \frac{K_r'\nu}{u_o^2}, \quad P_r = \frac{\mu C_p}{\kappa},$$
$$\theta = \frac{T - T_\infty}{T_w - T_\infty}, \quad C = \frac{C' - C'_\infty}{C'_w - C'_\infty}, \quad \omega = \frac{\omega'\nu}{u_o^2}, \quad \delta = \frac{Q\nu}{\rho C_p u_o^2}, \quad S_c = \frac{\nu}{D_m}$$
$$M = \frac{\nu\sigma B_o^2}{\rho u_o^2}, \quad F = \frac{D_m K_T(C'_w - C'_\infty)}{\nu C_s C_p(T_w - T\infty)}, \quad S_r = \frac{D_m K_T(C'_w - C'_\infty)}{\nu T_m(T_w - T\infty)},$$
$$N = \frac{k_m\kappa}{4\sigma_s T_\infty^3}, \quad G_r = \frac{g_x\beta_T\nu(T_w - T\infty)}{u_o^3}, \quad G_m = \frac{g_x\beta_m\nu(C'_w - C'\infty)}{u_o^3}$$

and with their help, and in view of Eq. (5) and Eq.(6), we write Eq. (1) to (3), the initial and boundary conditions Eq (4) as

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} - Mu + G_r\theta + G_m C \tag{7}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{P_r}\left(1 + \frac{4}{3N}\right)\frac{\partial^2\theta}{\partial y^2} + \delta\theta + F\frac{\partial^2 C}{\partial y^2}\ . \tag{8}$$

$$\frac{\partial C}{\partial t} = \frac{1}{S_c}\frac{\partial^2 C}{\partial y^2} - K_r C + S_r\frac{\partial^2\theta}{\partial y^2}\ . \tag{9}$$

The relevant initial and boundary conditions in non-dimensional form are:

$$\begin{aligned} &t \leqslant 0: \quad u = 0, \quad \theta = 0, \quad C = 0,\ \forall\ y\ , \\ &t > 0: \quad u = \cos\omega t, \quad \theta = t, \quad C = t, \quad at\ y = 0\ , \\ &\qquad u \to 0, \quad \theta \to 0, \quad C \to 0, \quad as\ y \to \infty\ . \end{aligned} \tag{10}$$

All the physical variables are defined in the nomenclature.

3. Method of Solution

The symbolic algebra software Maple17 was used to solve Equations (7) – (9) numerically subject to condition 10. The boundary conditions $y \longrightarrow \infty$ was replaced by far-field condition in accordance with the practice in the boundary layer analysis. Maple uses the theta method scheme to obtain the computed solution. Due to space and the rigorous proof, details of the solution method are omitted here. The step size 0.01 is used to obtain the numerical solution with high-decimal place accuracy as the criterion for convergence.

4. Results and Discussion

The distributions for the influence of selected physical parameters for the flow variables velocity u, temperature θ, and concentration C are presented graphically. The value of the Prandtl number is chosen as $P_r = 0.71$ for air characteristics at 20^oC. The value of the Schmidt number S_c chosen to represent the presence of diffusing chemical species of most common interest in air is hydrogen ($S_c = 0.22$). Here, the free convection parameter $(G_r, G_m) = 10$ corresponds to heating of the fluid or cooling of the plate. The values of Soret number S_r and Dufour number F are chosen to ensure that their product $(S_r * F)$ is constant whenever the mean temperature T_m is constant. Soret number takes values $2.0,\ 1.0,\ 0.5$ and Dufour number takes values $0.03,\ 0.06,\ 0.12$. In the absence of heat source we have $\delta = 0$ and $\delta = 2$ corresponds to source. The chemical reaction parameter K_r takes negative and positive values $0.5,\ 1.0,\ 2.0$ for exothermic and negative chemical reaction, respectively. For numerical computations, we utilized the following:

$$P_r = 0.71,\ \delta = 2.0,\ S_c = 0.22,\ K_r = 0.5,\ S_r = 1.0,\ M = 2.0,\ N = 3.0$$

$$G_r = 10.0,\ G_m = 10.0,\ F = 0.06,\ \omega t = \frac{\pi}{2}$$

unless stated otherwise.

The influence of Soret number on velocity, temperature and concentration profiles are shown in Figure 1, Figure 2 and Figure 3 respectively. It is seen that an increase in Soret number causes the deceleration of fluid motion while fluid temperature and concentration suffers a decrease.

The effect of Dufour number on velocity, temperature and concentration distribution is illustrated in Figure 4, Figure 5 and Figure 6, respectively. An increase in the Dufour number diminishes velocity and concentration profiles but enhances the fluid temperature.

Figure 7 and Figure 8 illustrates the collective influences of endothermic chemical

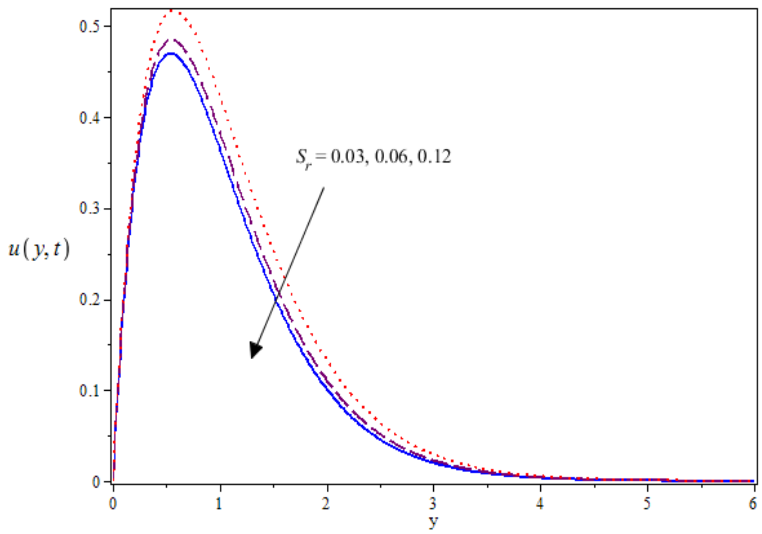

Figure 1: Effects of Soret number S_r on velocity profile u

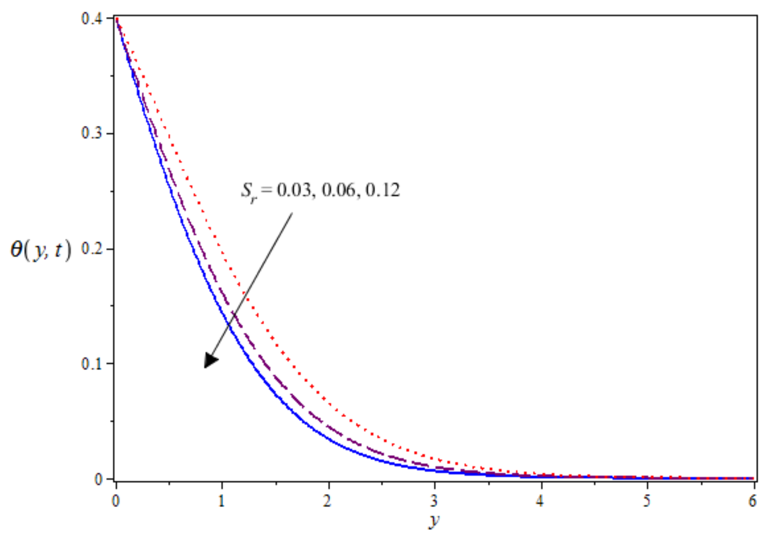

Figure 2: Effects of Soret number S_r on temperature profile θ

reaction and exothermic chemical reaction for velocity and concentration distribution, respectively. There is a clear increase in the velocity, that is, the flow is accelerated with endothermic chemical reaction, and decelerated in the presence of exothermic chemical reaction(Figure 7). We can see from Figure 8 that as the chemical reaction parameter increases, the concentration profile decreases

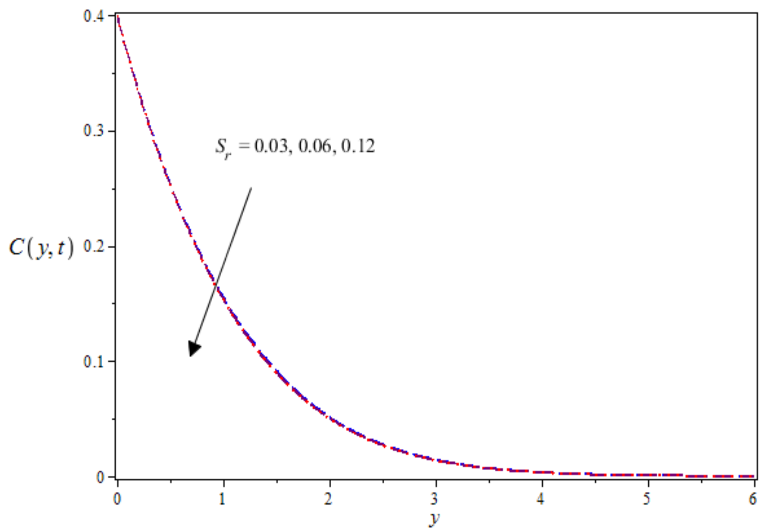

Figure 3: Effects of Soret number S_r on concentration profile C

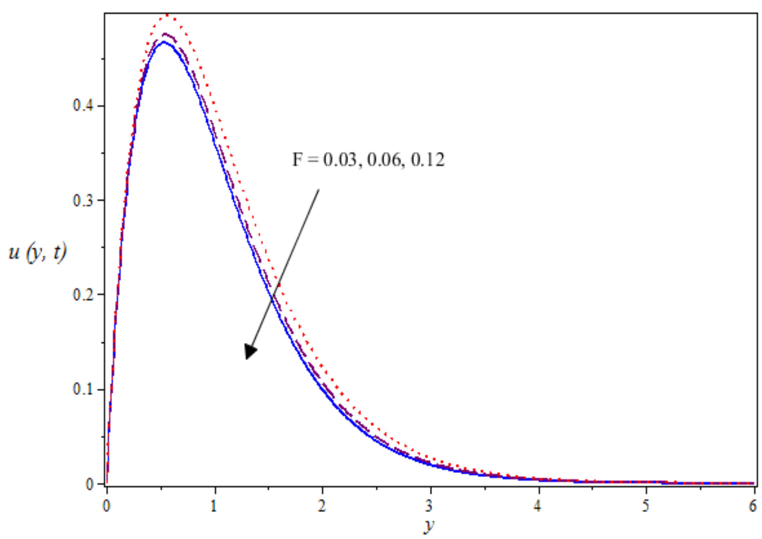

Figure 4: Effects of Dufour number F on velocity profile u

for endothermic chemical reaction and it is noticeably enhanced in the case of exhotermic chemical reaction.

Figure 9 and Figure 10 represents the velocity and temperature profiles, respectively. One can see clearly that increase in heat source parameter has the tendency to raise the fluid motion and temperature significantly. Figure 11 shows that concentration falls with changes in heat source parameter.

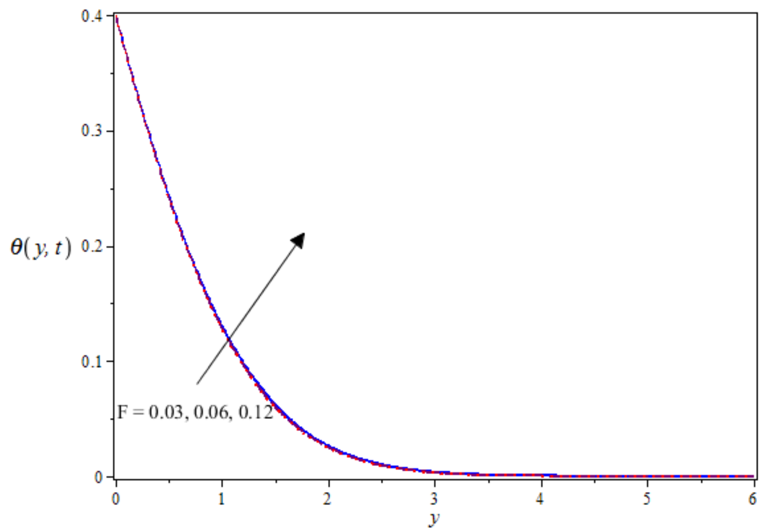

Figure 5: Effects of Dufour number F on temperature profile θ

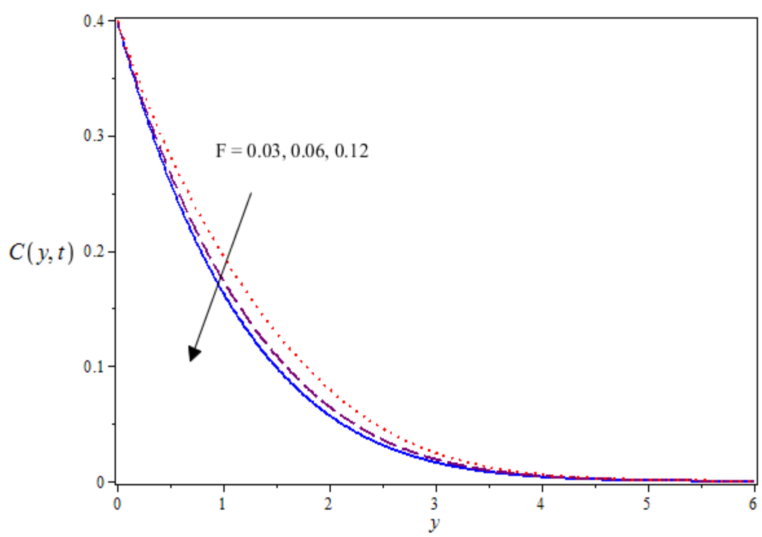

Figure 6: Effects of Dufour number F on concentration profile C

It is observed in Figure 12 that the velocity profiles decreases with an increase in Magnetic field parameter. This is due to the opposing nature of the magnetic force (i.e Lorentz force) as it is similar to the drag force which tends to resist flow or movement of fluids in any direction.
Figure 13, Figure 14 and Figure 15 depicts velocity, temperature and concentration profiles versus y, respectively, for different values of the radiation parameter.

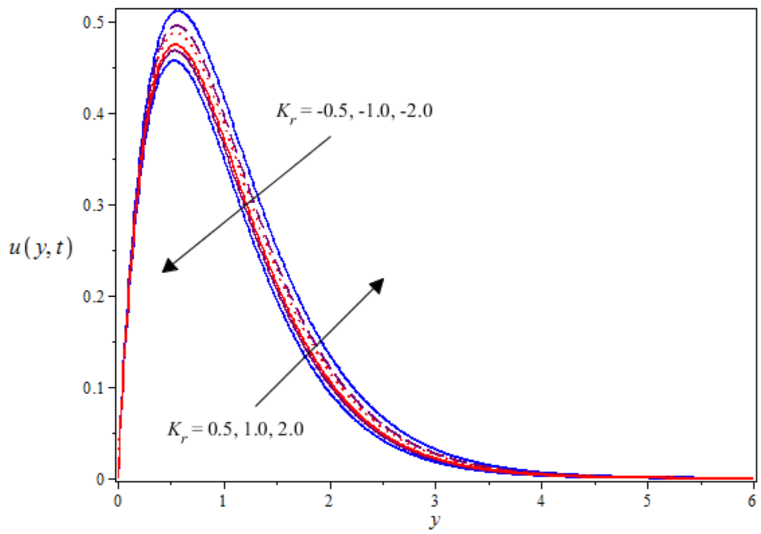

Figure 7: Effects of chemical reaction parameter K_r on velocity profile u

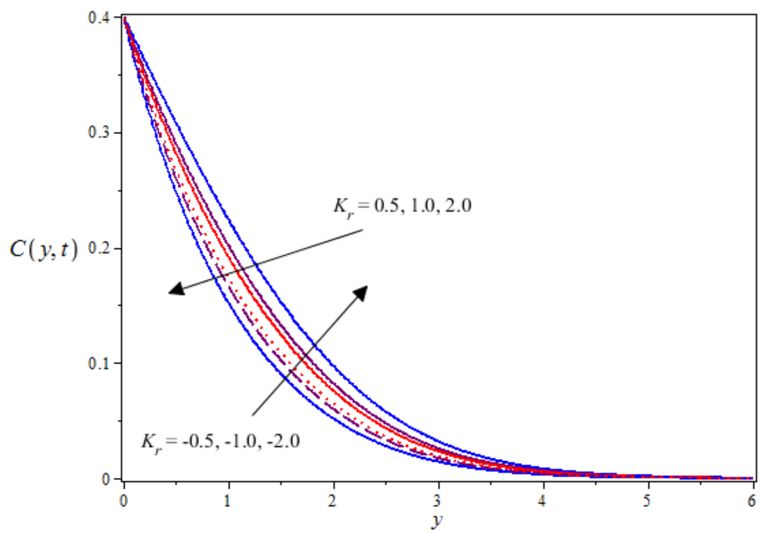

Figure 8: Effects of chemical reaction parameter K_r on concentration profile C

It is found that the fluid motion and temperature diminishes, whereas this behaviour is reversed in the case of concentration profile.

5. Conclusion

In this work, we have investigated the effect of Soret, Dufour and chemical reaction on viscous, incompressible radiating fluid past an oscillating plate with

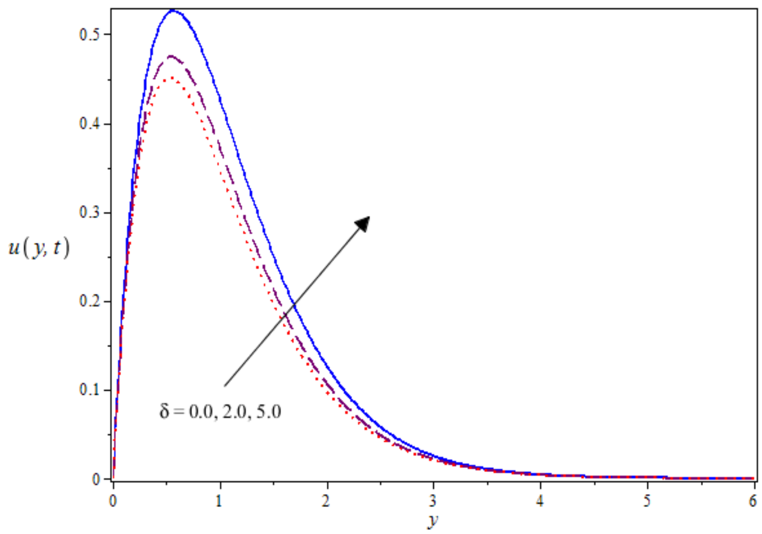

Figure 9: Effects of heat source parameter δ on velocity profile u

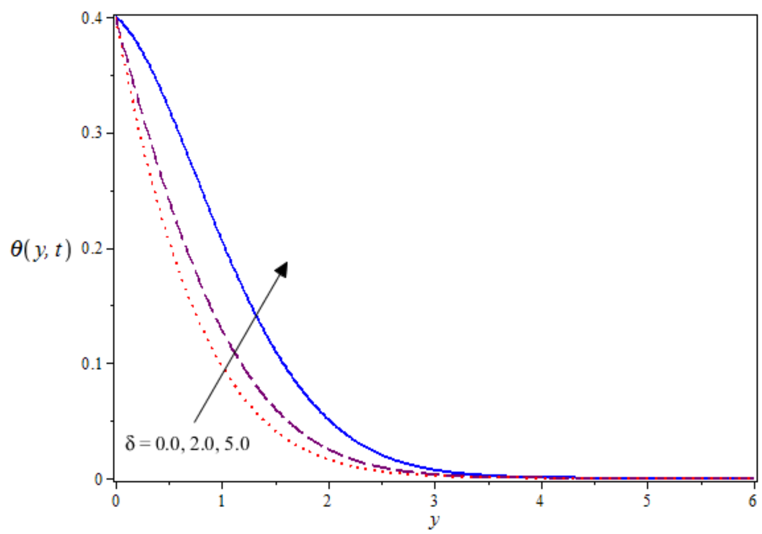

Figure 10: Effect of heat source parameter δ on temperature profile θ

heat source. The governing equations are solved using the Theta scheme on Maple17 platform. A comprehensive graphical representation of the solutions for the velocity, temperature and concentration profiles are presented

The following are the significant findings of this work:

- Soret number retard the velocity, temperature and concentration profiles.

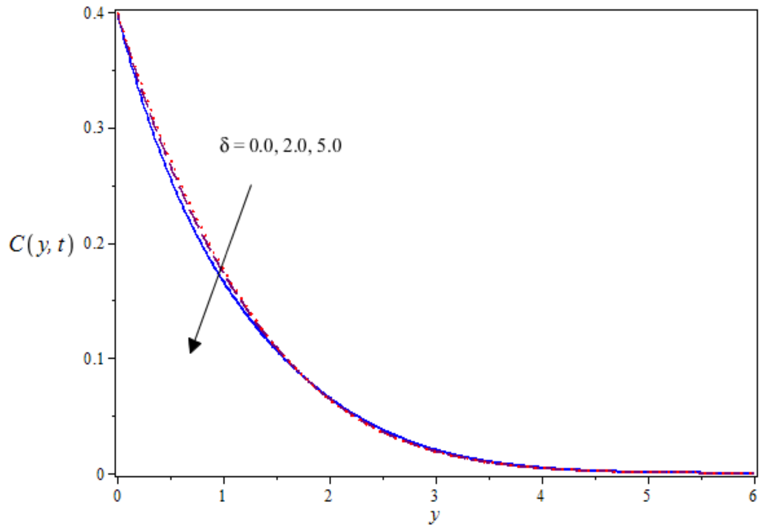

Figure 11: Effect of heat source parameter δ on concentration profile C

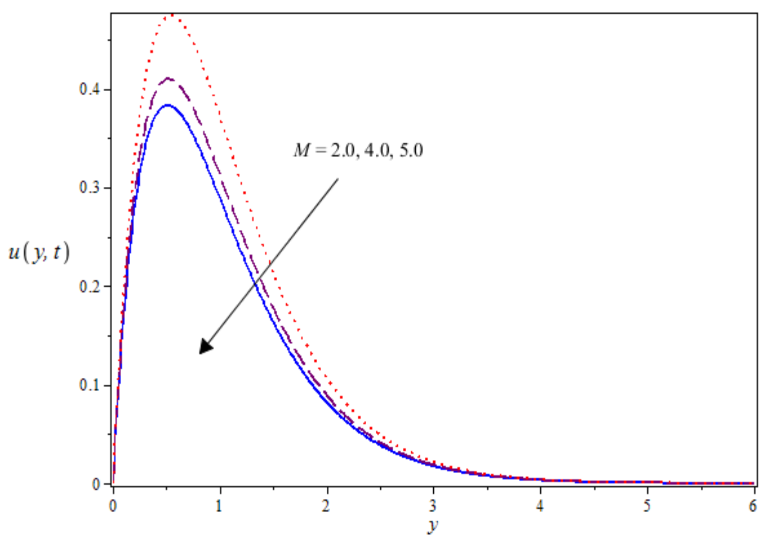

Figure 12: Effects of Magnetic field parameter M on velocity profile u

- An increase in Dufour number enhances temperature profiles but lead to a decrease in the velocity and concentration profiles.
- Fluid motion and fluid temperature experiences enhancement whereas concentration diminishes with changes in heat source parameter.
- Fluid motion decelerated, fluid temperature decrease and concentration leve enhance with increase in radiation parameter.

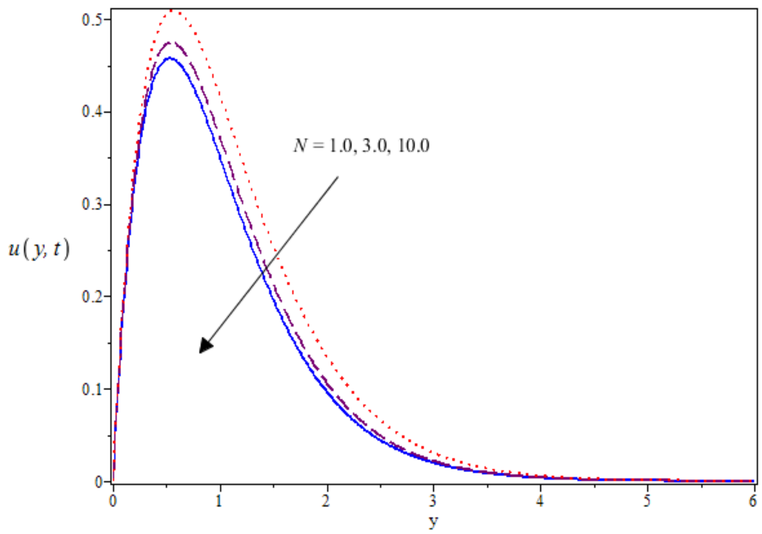

Figure 13: Effects of radiation parameter N on velocity profile u

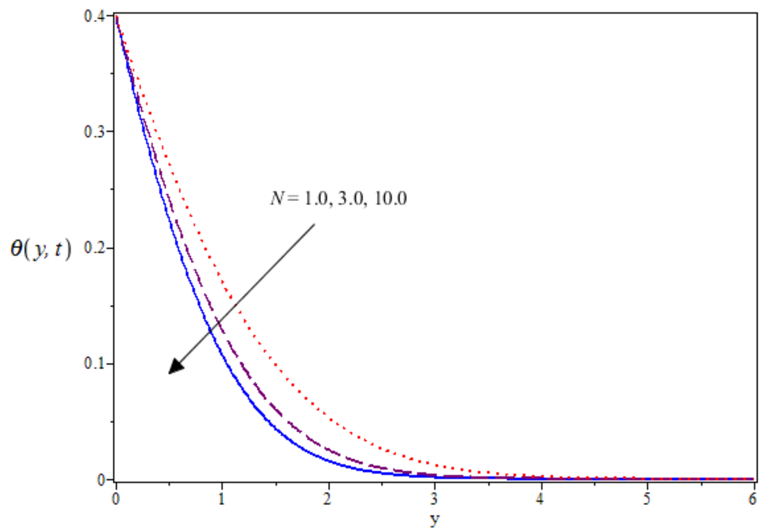

Figure 14: Effects of radiation parameter N on temperature profile θ

- Increase in Magnetic number leads to a decrease in the fluid motion.

References

[1] Ram P. C. (1991). Recent development of heat and mass transfer in hydromagnetic flows. Int. J. Energy Res.; **15**: 691-773.

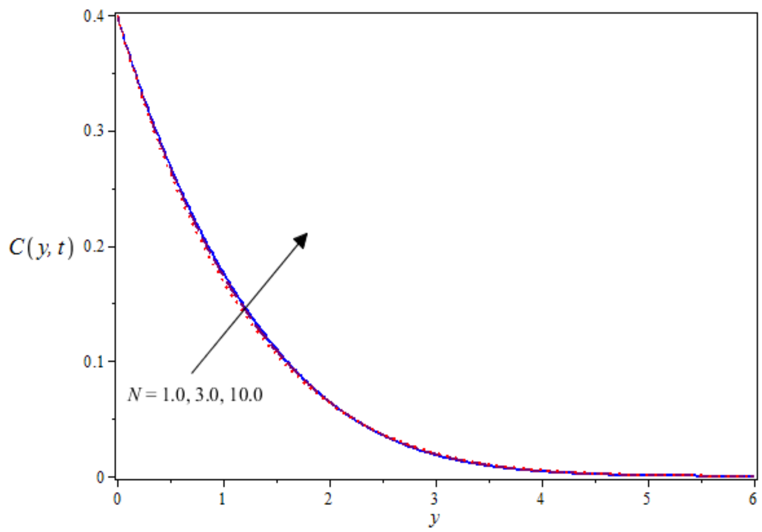

Figure 15: Effects of radiation parameter N on concentration profile C

[2] Chamkha A. J. and Khaled A. R. A. (2001). Similarity solutions for hydromafnetic simultaneous heat and mass transfer by natural convection from an inclined plate with internal heat generation or absorption. Heat Mass Transfer; **37**: 117-123.

[3] Chen C. H. (2004). Combined heat and mass transfer in MHD free convection from a vertical surface with ohmic and viscous dissipation. Int. J. Eng. Sci.; **48**:699-713.

[4] Alam MS, Ali M and Hossain MD. (2013). Heat and mass transfer in MHD free convection flow over an inclined plate with Hall current. The Int. J. Eng. and Sci.; **2** (7): 81-88.

[5] Rani K. J., Reddy G. V. R., Murthy C. V. R. and Murthy, M. V. R. (2015). Heat and mass transfer effects on MHD free convection flow over an inclined plate embedded in a porous medium. Int. J. Chem. Sci.; **13** (4): 1998-2016.

[6] Kristaiah P., Srinivas V. and Prasada Rao D. R. V. (2016). Effect of variable viscosity, dissipation and Hall currents on convection heat and mass transfer flow past a stretching sheet. Chemistry and Materials Res.; **8** (1): 1-15.

[7] Hemamalini P. T. and Kumar S. N. (2015). Heat and mass transfer effects on the unsteady MHD flow past an oscillating infinite vertical plate with variable temperature through the porous medium. Int J Sci and Res(IJSR); **4** (5): 1466-1470.

[8] Raptis A. and Massals C. V. (1998). Magnetohydrodynamic flow past a plate by the presence of radiation. Heat Mass Transfer; **34**: 107-109.

[9] Raptis A., Perdikis C. and Leontitsis A. (2003). Effect of radiation in an optically thin gray gas flowing past a vertical infinite plate in the presence of a magnetic field. Heat Mass Transfer; **39**: 771-773.

[10] Muthucumaraswamy R. and Meenakshisundaram S. (2006). Theoretical study of chemical reaction effects on vertical oscillating plate with variable temperature and mass diffusion. Theoret. Appl. Mech.; **3** (3): 245-257.

[11] Muthucumaraswamy R. and Janakiraman B. (2008). Mass transfer effect on isothermal vertical oscillating plate in the presence of chemical reaction. Int. J. Appl. Math. Mech.; **4** (1): 66-74.

[12] Sandeep N. and Sugunamma V. (2013). Aligned magnetic field and chemical reaction effects on flow past a vertical oscillating plate through porous medium. Commun. Appl. Sci.; **1** (1): 81-105.

[13] Sugunamma V., Sandeep N., Krishna P. M. and Bahunnadam R. (2013). Inclined magnetic field and chemical reaction effects on flow over a semi infinite vertical porous plate through porous medium. Commun. Appl. Sci.; **1** (1): 1-24.

[14] Kishore P. M., Varma S. V., Rao S. M. and Murugan K. S. B. (2014). The effect of chemical reaction on MHD free convection flow of dissipative fluid past an exponentially accelerated vertical plate. Int. J. Comput. Eng. Res.; **4** (1): 11-26.

[15] Sasikumar J. and Govindarajan A. (2015). Free convective MHD oscillatory flow past parallel plates in a porous medium with heat source and chemical reaction. Int. J. Sci. and Eng. Res.; **6** (3): 266-270.

[16] Rajput U. S. and Kumar G. (2016). Chemical reaction effect on unsteady MHD flow past an impulsively started oscillating inclined plate with variable temperature and mass diffusion in the presence of hall current. Appl. Res. J.; **2** (5): 244-253.

[17] Rajesh V. and Varma S. V. K. (2010). Radiation effects on MHD flow through a porous medium with variable temperature or variable mass diffusion. Int. J. Appl. Math. Mech.; **6** (1): 39-57.

[18] Kishore P. M., Rajesh V. and Verma S. V. (2010). Thermal stratification and viscous dissipation effects on MHD unsteady radiative natural convection flow past an infinite vertical accelerated plate embedded in a porous medium with variable surface temperature. Int. J. Math. Mech.; **6** (16): 1-18.

[19] Kishore P. M., Rajesh V. and Verma S. V. (2012). The effects of thermal radiation and viscous dissipation on MHD heat and mass diffusion flow past an oscillating vertical plate embedded in a porous medium with variable surface conditions. Theoret. Appl. Mech.; **39** (2): 99-125.

[20] Reddy P. S. and Prasada Rao D. R. V. (2010). Combined influence of Soret and Dufour effects on convective heat and mass transfer flow through a porous medium in cylindrical annulus with heat sources. African J. Math. and Comp. Sci. Res.; **3** (10): 237-254.

[21] El-Arabawy H. A. M. (2009). Soret and Dufour effects on natural convection flow past a vertical surface in a porous medium with variable surface temperature. J. Math. Sta.; **5** (3): 190-198.

[22] Sreenivasulu P. and Reddy N. B. (2012). Thermo-Diffusion and Diffusion-Thermo effects on MHD boundary layer flow past an exponential stretching sheet with thermal radiation and viscous dissipation. Adv. Appl. Sci. Res.; **3** (6): 3890-3901.

[23] Ojjela O. and Kumar N. N. (2014). Hall and ion slip effects on free convection heat and mass transfer of chemically reacting couple stress fluid in a porous expanding or contracting walls with Soret and Dufour effects. Frontiers Heat Mass Transfer (FHMT); **5** (22): 1-11.

[24] Sulochana C. and Tayappa H. (2015). Soret, Dufour and chemical reaction effects on convective heat and mass transfer over a stretching sheet with heat generating sources: A Lie Group Analysis. Chemical and Process Eng. Res.; **35**: 58-74.