KASU JOURNAL OF MATHEMATICAL SCIENCES

Unsteady Chemically Radiating Magneto-Hydrodynamics (Mhd) Oscillatory Flow In A Vertical Porous Channel With Suction/Injection Effects

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Abstract

Unsteady chemically radiating magneto-hydrodynamics (MHD) oscillatory flow in a vertical channel with Suction/injection effects have been investigated. The flow is laminar and incompressible. The temperatures prescribed at the channel walls are non – uniform. A uniform magnetic field is applied transverse to the channel. Non – dimensional parameters are used to non – dimensionalized the governing equations to dimensionless form. Closed form solution method is used to solve the dimensionless equations that govern the flow and the solutions for velocity, temperature and concentration distribution are obtained. The influence of flow parameters as they affect the velocity profile, temperature distribution, species concentration, skin friction, Nusselt number and Sherwood number are analysed and shown graphically in detail using MATLAB. Out of many results, it is concluded that the suction/injection parameter accelerates the velocity and elevates the temperature distribution and species concentration.

Keywords: MHD, oscillatory flow, suction/injection, chemical radiation, porous

1. Introduction

The study of unsteady chemically radiating magneto-hydrodynamics (MHD) oscillatory flow in a vertical channel with suction/injection effects is important in different areas such as MHD generators, arterial blood flow, petrochemical engineering etc. Suction/injection is the act or process of sucking. A force that causes a fluid or solid to be drawn into interior space or to adhere to surface because of the difference between the external and internal pressure.

The chemical reaction involves the process of transposition of the molecular structure of substances of different physical form. There are two types of reaction namely: homogeneous reaction that occurs uniformly in a given phase of flow and heterogeneous reaction that occurs in a particular region, Kumar (2015). There are several studies on the transfer of heat and mass in oscillatory flow problems; Falade et.al (2016) investigated the effect of suction / injection on the unstable oscillatory flow through a vertical channel with non-uniform wall temperature. The fluid is subjected to a transverse magnetic field and the velocity slip in the lower plate is taken into consideration. Exact solutions of the dimensionless equations governing fluid flow are obtained and the effects of flow parameters on temperature, velocity profiles, skin friction and heat transfer rate are discussed and graphically displayed. They noted that the friction of the skin increases in both channel plates as the injection in the heated plate increases. Dulal and Sukanta (2018) investigated the double diffusion mass and heat transfer characteristics of an electrically viscous oscillating micro polar fluid on a moving plate with convective contour condition and chemical reaction. The non-linear partial differential equations are first converted into ordinary nonlinear differential equations by perturbation analysis and the control equations are solved analytically. The effects of the magnetic field, the chemical reaction, the permeability parameter, the Prandtl number, the Schmidt number, the thermal radiation and the viscosity parameter are analyzed in the skin friction, the Nusselt number, the velocity and the temperature and concentration distributions. They observed that the concentration profiles decrease with the increase of the time without dimensions and increase with the increase of the chemical reaction parameter. They also observed that the velocity profile increases with increasing time, but inverse effects are found by increasing the value of the viscosity ratio parameter. In addition, it is observed that the effect of the magnetic field parameter is to increase the micro-rotation speed profiles, but the inverse effect is observed when the time increases. Makinde and Mhone (2005) investigated MHD oscillatory fluid by forced convection through a channel filled with porous media. It was assumed that the channel plates are waterproof. Mehmood and Ali (2007) investigated the effect of sliding on the free convective oscillatory flow through the vertical channel with periodic temperature and dissipative heat. Chauchau and Kumar studied the constant flow and heat transfer in a composite vertical channel (2011). Idowu et.al (2015) investigated the effect of variable suction and chemical reaction on the MHD oscillatory flow through a vertical porous plate with heat generation. The control equations of the flow field are solved using the perturbation technique and the expressions of speed, temperature and concentration of species. Daniel et al (2014) studied the sliding effect in the oscillatory fluid flow MHD in a porous channel with heat and mass transfer and chemical reaction. They assumed that the temperature prescribed in the plates is uniform and asymmetric. They used a closed form analytical method to solve the impulse and energy equations. Palani and Abbas investigated the combined effects of magneto-hydrodynamics and the effect of radiation on the free convection flow that passes through an isothermal vertical plate impulsively initiated using the Rosseland approach (2009). Hussain et al (2010) presented an analytical study of the second degree oscillatory fluid flow in the presence of a transverse magnetic field. Idowu et.al

(2013) studied the effect of heat and mass transfer on the unstable MHD oscillatory flow of Jeffrey's fluid in a horizontal channel with chemical reaction. The temperature prescribed in the plates is uniform and asymmetric. A perturbation method is used to solve the momentum, energy and concentration equations. Skin frictions, Nusselt numbers and Sherwood numbers are evaluated using the perturbation technique. The effects of several dimensionless parameters in the velocity and temperature profiles are considered and discussed in detail through graphs and tables. Umavathi et.al (2009) investigated the unstable flow of viscous fluid through a horizontal composite channel whose average width is filled with porous medium. Adesanya and Makinde investigated the effect of radiation heat transfer on the pulsatile couple's stress fluid flow with a time-dependent limit condition on the heated plate (2012). They affirmed that the non-slip condition is not realistic in some flows that involve nano-channels, micro-channels and flows on plates coated with hydrophobic substances. Briefly, Adesanya and Gbadeyan (2010) studied the flow and heat transfer of a non-Newtonian constant fluid flow by observing the sliding of the fluid in the channel.

Therefore, the aim of this work is to review and extend the study by Falade et.al (2016).

2. Mathematical analysis/Problem formulation

We consider an electrically viscous incompressible fluid through a vertical porous channel. The flow is laminar and unstable with the condition of no sliding on the heated plate and sliding on the cold plate. A magnetic field B_0 of uniform force is applied transversely to the channel. It is assumed that the fluid has a small electrical conductivity and that the electromagnetic force produced is very small. The flow is subjected to suction in the cold wall and injection into the hot wall. The flow of the fluid is along the vertical direction under a chemical reaction with species concentration C' as shown in figure 1. The channel width is twice $y' = a$.

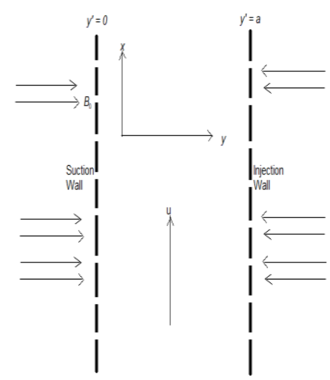

Figure 1: Physical diagram of the problem

The governing equations of the flow field subject to Bousinesq approximation are

$$\frac{\partial u'}{\partial t'} - v_0 \frac{\partial u'}{\partial y'} = -\frac{1}{\rho}\frac{dP}{dX} + \nu \frac{\partial^2 u'}{\partial y'^2} - \frac{\nu}{K} u' - \frac{\sigma_e B_0^2}{\rho} u' + g\beta(T' - T_0') + g\beta^*(C' - C_0') \quad (1)$$

$$\frac{\partial T'}{\partial t'} - v_0 \frac{\partial T'}{\partial y'} = \frac{k_f}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} - \frac{4\alpha^2}{\rho C_p}(T' - T_0') \quad (2)$$

$$\frac{\partial C'}{\partial t'} - v_0 \frac{\partial C'}{\partial y'} = D\frac{\partial^2 C'}{\partial y'^2} - K_r'(C' - C_0') \quad (3)$$

With the boundary conditions

$$u' = \frac{\sqrt{K}}{\alpha_s}\frac{du'}{dy'},\ T' = T_0',\ C' = C_0' \quad \text{on} \quad y' = 0 \qquad (4)$$

$$u' = 0, T' = T_1',\ C' = C_1' \text{ on } y' = a \quad (5)$$

In order to write equations (1) to (5) in dimensionless form we use the following dimensionless parameters and variables

$$x' = \frac{x'}{h}, y' = \frac{y'}{h}, u = \frac{hu'}{\nu}, t = \frac{\nu t'}{h^2}, P = \frac{h^2 P}{\rho \nu^2}, Gr = \frac{g\beta(T_0' - T_0')h^3}{\nu^2}, Gc = \frac{g\beta^*(C_0' - C_0')h^3}{\nu^2}, Pr = \frac{\rho C_p \nu}{k}, \theta = \frac{T' - T_0'}{T_1' - T_0'}, \phi = \frac{C' - C_0'}{C_1' - C_0'}, \delta = \frac{4\alpha^2 h^2}{\rho C_p \nu}, \gamma = \frac{\sqrt{K}}{\alpha_s h}, Ha^2 = \frac{\sigma_e B_0^2 h^2}{\rho \nu}, Da = \frac{K}{h^2}, s = \frac{v_0 h}{\nu}, Sc = \frac{\nu}{D} \qquad (6)$$

Equations (1) to (5) become

$$\frac{\partial u}{\partial t} - s\frac{\partial u}{\partial y} = -\frac{dP}{dx} + \frac{\partial^2 u}{\partial y^2} - \left(Ha^2 + \frac{1}{Da}\right)u + Gr\theta + Gc\phi \qquad (7)$$

$$\frac{\partial \theta}{\partial t} - s\frac{\partial \theta}{\partial y} = \frac{1}{Pr}\frac{\partial^2 \theta}{\partial y^2} + \delta\theta \qquad (8)$$

$$\frac{\partial \phi}{\partial t} - s\frac{\partial \phi}{\partial y} = \frac{1}{Sc}\frac{\partial^2 \phi}{\partial y^2} - K_r\phi \qquad (9)$$

The boundary conditions now become

$$u(0) = \gamma\frac{du(0)}{dy}, \theta(0) = 0, \phi(0) = 0 \quad (10)$$

$$u(1) = 0, \theta(1) = 1, \phi(1) = 1 \qquad (11)$$

Methodology/Solution of the Problem

As shown in Falade et.al [2], for purely oscillatory flow, the solutions of the dimensionless equations (7) – (9) are presented as

$$-\frac{dP}{dx} = \lambda e^{i\omega t}, u(y,t) = u_0(y)e^{i\omega t}, \theta(y,t) = \theta_0(y)e^{i\omega t}, \phi(y,t) = \phi_0(y)e^{i\omega t} \qquad (12)$$

Where λ is any positive constant and ω is the frequency of oscillation.

By putting equations (12) into equations (7) – (11), we have the following differential equations

$$\frac{\partial^2 u_0}{\partial y^2} + s\frac{\partial u_0}{\partial y} - A_2 u_0(y) = -\lambda - Gr\theta_0(y) - Gc\phi_0(y) \qquad (13)$$

$$\frac{\partial^2 \theta}{\partial y^2} + A_3\frac{\partial \theta}{\partial y} + A_4\theta_0(y) = 0 \qquad (14)$$

$$\frac{\partial^2 \phi_0}{\partial y^2} + s\frac{\partial \phi_0}{\partial y} - A_5\phi_0(y) = 0 \qquad (15)$$

The corresponding boundary conditions in equations (11) and (12) become

$$u_0(0) = \gamma\frac{du_0}{dy}, \theta_0(0) = 0, \phi_0(0) = 0 \qquad (16)$$

$$u_0(1) = 0, \theta_0(1) = 0, \phi_0(1) = 0 \qquad (17)$$

Since, equation (13) is a coupled differential equation; we first solve equations (14) and (15). Thus, the solutions are as follows;

$$\phi_0(y) = c_1 e^{m_1 y} + c_2 e^{m_2 y} \qquad (18)$$

$$\theta_0(y) = c_3 e^{m_3 y} + c_4 e^{m_4 y} \qquad (19)$$

$$u_0(y) = c_5 e^{m_5 y} + c_6 e^{m_6 y} + K_0 + K_1 e^{m_1 y} + K_2 e^{m_2 y} + K_3 e^{m_3 y} + K_4 e^{m_4 y} \qquad (20)$$

Therefore, the analytical solutions for velocity, temperature and concentration distribution are

$$u(y,t) = (c_5 e^{m_5 y} + c_6 e^{m_6 y} + K_0 + K_1 e^{m_1 y} + K_2 e^{m_2 y} + K_3 e^{m_3 y} + K_4 e^{m_4 y}) e^{i\omega t} \quad (21)$$

$$\theta(y,t) = (c_3 e^{m_3 y} + c_4 e^{m_4 y}) e^{i\omega t} \quad (22)$$

$$\phi(y,t) = (c_1 e^{m_1 y} + c_2 e^{m_2 y}) e^{i\omega t} \quad (23)$$

SKIN FRICTION τ

The shear stress is obtained as

$$\tau = \frac{\partial u}{\partial y} = (c_5 m_5 e^{m_5 y} + c_6 m_6 e^{m_6 y} + K_1 m_1 e^{m_1 y} + K_2 m_2 e^{m_2 y} + K_3 m_3 e^{m_3 y} + K_4 m_4 e^{m_4 y}) e^{i\omega t} \quad (24)$$

NUSSELT NUMBER Nu

The Nusselt number is obtained as

$$Nu = -\left(\frac{\partial \theta}{\partial y}\right) = -(c_3 m_3 e^{m_3 y} + c_4 m_4 e^{m_4 y}) e^{i\omega t} \quad (25)$$

SHERWOOD NUMBER Sh

The Sherwood number is obtained as

$$Sh = -\left(\frac{\partial \phi}{\partial y}\right) = -(c_1 m_1 e^{m_1 y} + c_2 m_2 e^{m_2 y}) e^{i\omega t} \quad (26)$$

3. Data Presentation and Discussion of Results

The unsteady chemically radiating magneto-hydrodynamics (MHD) oscillatory flow in a vertical porous channel with suction/injection effects has been analysed, the velocity u, the temperature θ and the concentration of species ϕ plot profiles are plotted against y and for different values of the parameter of suction/injection s, slip parameter γ, pressure gradient λ, Hartmann number Ha, Darcy parameter Da, Grashof numbers $Gc \text{ and } Gr$, thermal radiation δ, chemical parameter K_r and frequency oscillation ω.

3.1 Velocity Profile

The magnitude of the fluid velocity varies with different values of suction/injection parameter s, slip parameter γ, pressure gradient λ, Hartmann number Ha, Darcy parameter Da, Grashof numbers $Gc \text{ and } Gr$, thermal radiation δ and chemical parameter K_r. These are analysed in figures 2 – 10.

Figure 2 demonstrates plot of velocity $u(y,t)$ against y showing s on fluid velocity u. It is seen that u increases with increase in s. This means that the difference between the external and internal pressure enhances the flow of the fluid.

Figure 3 shows the influence of slip flow parameter γ on fluid velocity u. It is observed that as the slip parameter increases, the fluid velocity increases. This is due to the porosity of the channel.

Figure 4 demonstrates the influence of λ on fluid velocity. It is seen that the fluid velocity increases as λ increases.

Hartmann number Ha retards the fluid velocity u. This is shown in figure 5.

The influence of Darcy parameter Da on fluid velocity u is shown in figure 6. Since, it is evident that increase in Da increases u.

Figure 7 demonstrates the effect of Grashof number Gr due to heat transfer on fluid velocity u. It is evident that as Gr increases, u increases.

Effect of thermal radiation δ on fluid velocity u is demonstrated in figure 8. Velocity of the fluid u increases as δ increases.

Influence of modified Grashof number Gc due to mass transfer on fluid velocity u is illustrated on figure 9. It can be seen that u increases as Gc increases.

The plot showing the influence of chemical reaction parameter K_r on fluid velocity u is illustrated in figure 10. It is can be seen that u increases with increase in K_r.

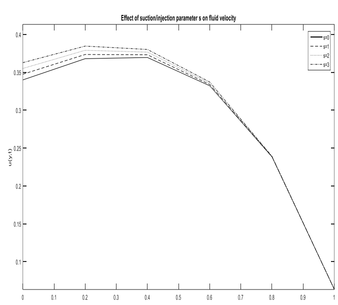

Figure 2: Plot of velocity $u(y,t)$ against y showing influence s on u with $Da = 1, \delta = 1, Ha = 1, \lambda = 1, \gamma = 0.1, Gr = 1, Gc = 1, \omega = \pi, Pr = 0.71, K_r = 1, Sc = 1 \; and \; t = 0$

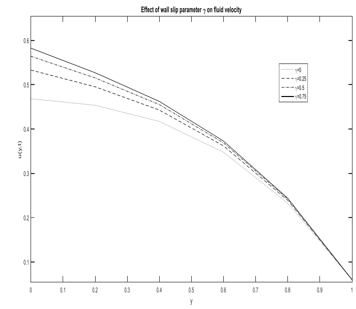

Figure 3: Plot of velocity $u(y,t)$ against y showing influence of wall slip parameter γ on fluid velocity with $Da = 1, \delta = 1, Ha = 1, \lambda = 1, s = 1, Gr = 1, Gc = 1, \omega = \pi, Pr = 0.71, K_r = 1, Sc = 1 \; and \; t = 0$

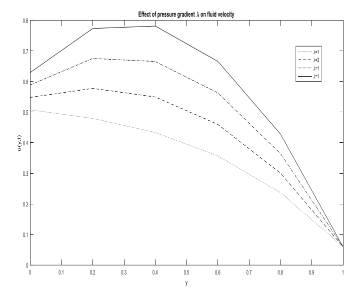

Figure 4: Plot of velocity $u(y,t)$ against y showing effect of pressure gradient λ on fluid velocity with $Da = 1, \delta = 1, Ha = 1, \gamma = 1, s = 1, Gr = 1, Gc = 1, \omega = \pi, Pr = 0.71, K_r = 1, Sc = 1 \; and \; t = 0$

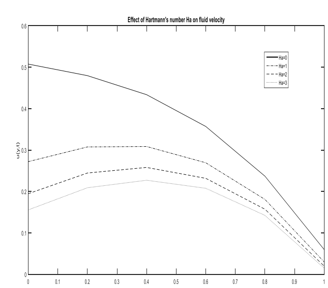

Figure 5: Plot of velocity $u(y,t)$ against y showing influence of Hartmann's number Ha on fluid velocity with $K_r = 1,\; Gc = 1,$ $Pr = 0.71,\; \gamma = 1,\; s = 1,\; Gr = 1,\; \delta = 1,$

$\omega = \pi,\ \lambda = 1,\ Da = 1,\ Sc = 1\ and\ t = 0$

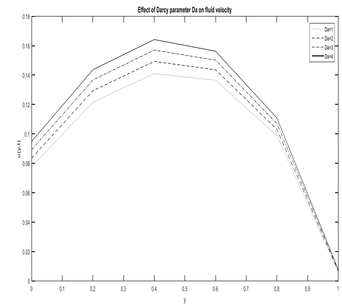

Figure 6: Plot of velocity $u(y,t)$ against y showing effect of Darcy parameter Da on fluid velocity with $Gc = 1,\ Sc = 1,\ s = 1,\ \gamma = 1,\ Gr = 1,\ Ha = 1,\ \omega = \pi,\ Pr = 0.71, K_r = 1, \delta = 1\ and\ t = 0$

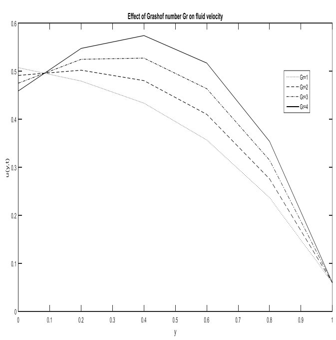

Figure 7: Plot of velocity $u(y,t)$ against y showing influence of Gr on u with $\lambda = 1,\ \gamma = 1, s = 1, Da = 1\ , Ha = 1,\ \delta = 1,\ Gc = 1, \omega = \pi,\ Pr = 0.71, K_r = 1,\ Sc = 1\ and\ t = 0$

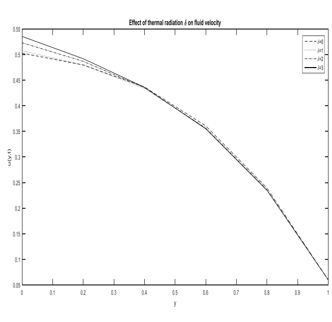

Figure 8: Plot of velocity $u(y,t)$ against y showing influence of thermal radiation δ on fluid velocity with $, Gr = 1, \lambda = 1,\ \gamma = 1, s = 1,\ Ha = 1,\ Da = 1, Gc = 1, \omega = \pi, Pr = 0.71, K_r = 1, Sc = 1\ and\ t = 0$

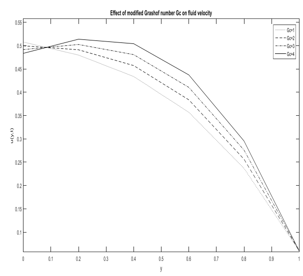

Figure 9: Plot of velocity $u(y,t)$ against y showing influence of Gc on u with $Ha = 1, Gr = 1, \lambda = 1,\ \gamma = 1, s = 1, Da = 1, \delta = 1, \omega = \pi, Pr = 0.71, K_r = 1, Sc = 1\ and\ t = 0$

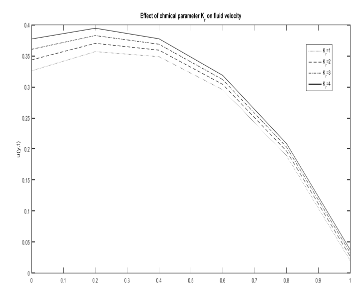

Figure 10: Plot of velocity $u(y,t)$ against y showing influence of chemical parameter K_r on fluid velocity with $Gr = 1, \lambda = 1,\ \gamma = 1, s = 1, Da = 1,\ Ha = 1,\ \delta = 1, \omega = \pi, Pr = 0.71, Gc = 1, Sc = 1\ and\ t = 0$

3.2 Temperature Profile

The magnitude of the fluid temperature is also affected with different values of thermal radiation parameter δ, suction/injection parameter s and frequency of oscillation ω.

Figure 11 illustrates influence of s on θ. It is observed that θ increases with increase in s.

Figures 12 and 13 show the effects of δ and ω respectively. It is evident that increase in both the flow parameters decrease the fluid temperature.

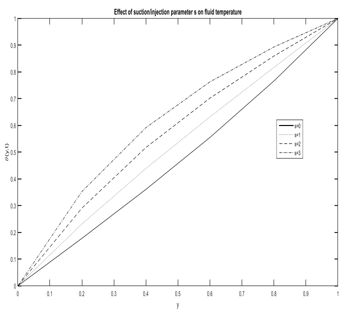

Figure 11: Plot of temperature $\theta(y,t)$ against y showing effect s on θ with $\delta = 1, Pr = 0.71, \omega = \pi \ and \ t = 0$

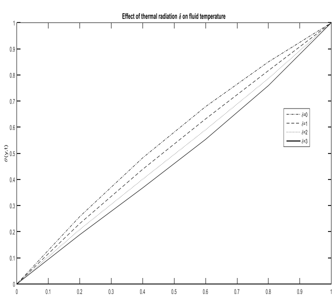

Figure 12: Plot of temperature $\theta(y,t)$ against y showing effect of thermal radiation δ with $s = 1, Pr = 0.71, \omega = \pi \ and \ t = 0$

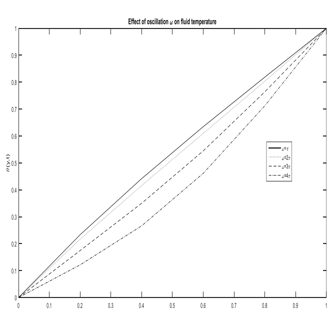

Figure 13: Plot of temperature $\theta(y,t)$ against y showing effect of oscillation ω on fluid temperature with $s = 1, Pr = 0.71, \delta = 1 \ and \ t = 0$

3.3 Concentration Distribution

The concentration distribution is also affected by suction/injection parameter s, chemical parameter K_r and frequency of oscillation ω.

Figure 14 illustrates the influence of suction/injection s on ϕ. It is evident that increase in s increases ϕ.

Figures 15 and 16 illustrate effect of chemical parameter K_r and frequency of oscillation ω on concentration distribution. As illustrated, increase in both parameters decrease ϕ.

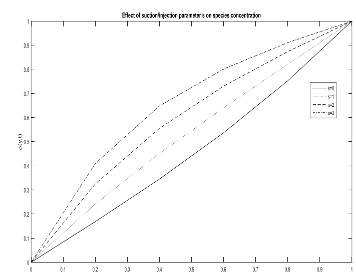

Figure 14: Plot of concentration distribution $\phi(y,t)$ against y showing influence s on ϕ with $K_r = 1, \omega = \pi, Sc = 1 \ and \ t = 0$

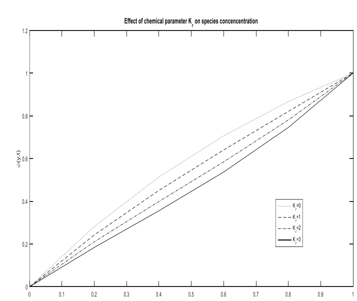

Figure 15: Plot of concentration distrbution $\phi(y,t)$ against y showing effect K_r on ϕ with $s = 1, \omega = \pi, Sc = 1$ and $t = 0$

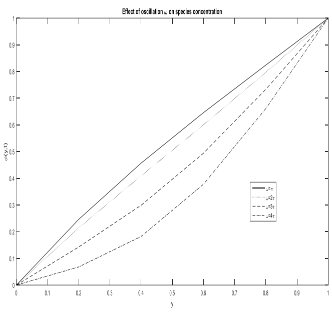

Figure 16: Plot of concentration distribution $\phi(y,t)$ against y showing effect of oscillation ω on species concentration with $s = 1, K_r = 1, Sc = 1$ and $t = 0$

4.4 Skin Friction τ, Nusselt Number Nu And Sherwood Number Sh

Figures 17, 18 and 19 depict the plots of τ, Nu and Sh against y with influence of suction/injection s respectively.

It can be deduced from figure 17 that τ increases as the suction/injection s increases.

It is also observed from figure 18 that increase in suction/injection parameter s increases the Nusselt number Nu at the cold wall and increases at the heated wall.

In figure 19, it is evident that as the suction/injection parameter s increases, the Sherwood number Sh increases at the lower plate and decreases at the upper plate.

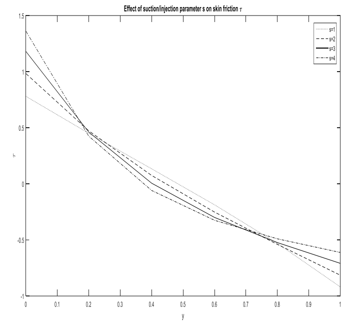

Figure 17: Plot of Skin friction τ agains y showing influence of s on τ with $Ha = 1, Gr = 1, \lambda = 1,\ \gamma = 1, Gc = 1, Da = 1, \delta = 1, \omega = \pi, Pr = 0.71, K_r = 1, Sc = 1$ and $t = 0$

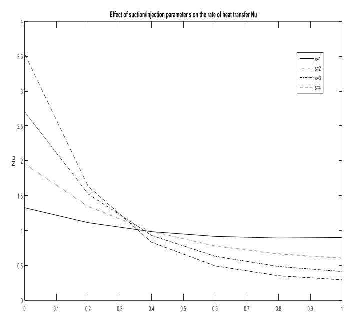

Figure 18: Plot of Nusselt number Nu showing influence s on Nu with $\omega = \pi, Pr = 0.71, \delta = 1$ and $t = 0$

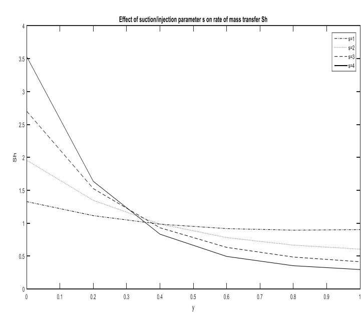

Figure 19: Plot of Sherwood number Sh against y showing influence of s Sh with $\omega = \pi, K_r = 0.71, Sc = 1$ and $t = 0$

4. Conclusion

The unsteady chemically radiating magnto-hydrodynamics oscillatory flow in a vertical channel with suction/injection effects has been investigated. The channel is porous and we assumed laminar and incompressible flow. The temperatures prescribed at the channel walls are non – uniform. Magnetic field strength which is uniform is applied transversely to the channel. Dimensionless parameters are used to non – dimensionalized the governing equations to dimensionless form. Closed form solution method is used to solve the dimensionless equations govern the flow and the solutions for velocity, temperature and concentration distribution are obtained. The effects of flow parameters on velocity profile, temperature distribution, species concentration, skin friction, Nusselt number and Sherwood number are presented, discussed and shown graphically in details. The results of this work is in agreement with the results obtained in [2] when $K_r = 0$.

It can be concluded that:

(i) Increase in s accelerates the velocity of the fluid.

(ii)Increase in s elevates the temperature distribution

The concentration distribution elevates with higher value of suction and injection parameter

(i) Increase in s accelerates τ on upper and lower plates

(ii) Nusselt number increases at the cold plate and decreases it at the heated plate with higher values of suction and injection parameter

(iii) Higher values of s increase the Sherwood number at cold plate and decreases it at the heated plate. This work can be extended further for studies such as viscous dissipation and suction/injection on unsteady chemically radiating magneto-hydrodynamics oscillatory flow in a vertical channel. This can be done by adding $\left(\frac{\partial u}{\partial y}\right)^2$ to the energy equation.

Nomenclature

t'	Time
u'	Velocity of the fluid
v_0	Uniform velocity
ρ	Density of the fluid
P'	Pressure of the fluid
β	Volumetric expansion due to heat transfer
β^*	Volumetric expansion due to concentration
C_p	Specific heat at constant pressure
α	Thermal radiation term
k	Thermal conductivity
T'	Fluid temperature
T_0	Referenced temperature
C'	Concentration of the fluid
K_r'	Chemical reaction
D	Mass diffusivity.

Appendix A

$$A_1 = Ha^2 + \frac{1}{Da}, A_2 = A_1 + i\omega, A_3 = sPr, A_4 = P\,r(\delta - i\omega), A_5 = K_r + i\omega, c_1 = \frac{1}{e^{m_1} - e^{m_2}}, c_2 = -c_1, c_3 = \frac{1}{e^{m_3} - e^{m_4}}, c_4 = -c_3, c_5 = \frac{A_8 - A_{10}c_6}{A9}, c_6 = \frac{A_{10}e^{m_5} - A_9 e^{m_6}}{A_{10}e^{m_5} - A_9 e^{m_6}}, m_1 = \frac{-s + \sqrt{s^2 + 4A_5}}{2}, m_2$$

$= \frac{-s-\sqrt{s^2+4A_5}}{2}, m_3$
$= \frac{-A_3+\sqrt{A_3^2-4A_4}}{2}, m_4$
$= \frac{-A_3-\sqrt{A_3^2-4A_4}}{2}, m_5$
$= \frac{-s+\sqrt{s^2+4A_2}}{2}, m_6 = \frac{-s-\sqrt{s^2+4A_2}}{2},$

$$K_0 = \frac{\lambda}{A_2}, K_1 = \frac{-Gcc_1}{m_1^2 + sm_1 - A_2}, K_2 = \frac{-Gcc_2}{m_2^2 + sm_2 - A_2}$$

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