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Effects of Suction/Injection on Free Convective Radiative Flow In A Vertical Porous Channel With Mass Transfer And Chemical Reaction

¹Usman Halima, Tasi'u Ahmad Rufa'I and ²Emmanuel Omokhuale

¹Department of Mathematics, Usmanu Danfodiyo University, P.M.B. 2346, Sokoto, Nigeria

²Department of Mathematical Science, Federal University, Gusau, P.M.B. 1001, Zamfara State, Nigeria

Corresponding Author's Email: usmanhalima6@gmail.com

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ABSTRACT

This paper presents an analysis of the effect of suction/injection on free convective flow past a vertical porous plate under the action of thermal radiation and chemical reaction when heat is supplied to the plate at constant rate. The governing equations are solved using implicit finite difference method. The results are obtained for the velocity, temperature, concentration, skin-friction, Nusselt number, and Sherwood number. The effects of various parameters on flow variables are illustrated physically, and the physical aspects of the problem are discussed. During the course of numerical computation, it was found that the velocity and temperature profiles increase with an increase in suction/injection parameter. Also, the skin-friction and rate of heat transfer increase with increase in radiation parameter and it shows reverse effect in the case of Sherwood number.

Keywords: Free-convection, vertical channel, suction/injection, thermal radiation, mass transfer, chemical reaction.

1.0 INTRODUCTION

Analysis of fluid flow and heat mass transfer in different geometries has been a subject of considerable interest due to its wide range of applications in engineering, science and technology, such as thermal insulations, geothermal systems, nuclear waste disposal, micro electric heat transfer equipment, coal and grain storage, petroleum industries, etc. In many transport processes in nature and in industrial applications in, which heat and mass transfer is a consequence of buoyancy effects caused by diffusion of heat and chemical species. The study of such processes is useful for improving a number of chemical technologies, such as polymer production and food processing.

Considerable attention was devoted to study thermal radiation because of its effect in high operating temperature process. For example, in Pathak and Maheshwari (2006) investigated the influence of radiation on an unsteady free convection flow bounded by an oscillating plate with variable wall temperature. Usman *et al.* (2016) analyzed a study on heat and mass transfer along vertical channel in porous medium with radiation effect and slip condition. Also, Shateyi (2008) studied the effects of thermal radiation, buoyancy and suction/blowing on natural convection heat and

mass transfer over a semi- infinite stretching surface. Besides, Suneetha *et al.* (2008) analyzed the radiation effects on the MHD free convection flow past an impulsively started vertical plate with variable surface temperature and concentration. In recent works on free convective flow in presence of thermal radiation, Ogulu and Makinde (2008) studied the effect of thermal radiation and absorption an unsteady free convective flow past a vertical plate in the presence of a magnetic field and constant wall heat flux. Similarly, Fahad *et al.* (2017) presented an analysis on the effects of suction/injection and radiation on the MHD Marangoni convection boundary layer heat and mass transfer with joule heating and viscous dissipation. In another article, Kandasamy *et al.* (2007) investigated heat and mass transfer along a wedge with variable surface tension and heat radiation in the presence of suction/injection. Rehman *et al.* (2019) examined suction/injection effects on an unsteady MHD Casson thin film flow with slip and uniform thickness over a stretching sheet along variable flow properties. Prasad *et al.* (2020) discussed the importance on the impact of suction/injection and heat transfer on unsteady MHD flow over a stretchable rotating disc. Uwanta and Usman (2014) scrutinized on the influence of Soret and Dufour effects on MHD free convective heat and mass

transfer flow over a vertical channel with constant suction and viscous Dissipation

The chemical reaction is among the most important factors that influence the reaction rate. It plays a key role in the transmission of heat and mass transfer in a vertical channel. It has a vital role in several applications, which include the manufacturing industry, major engineering activities such as drying, temperature, and moisture distribution that can be carried out using heat and mass transfer due to chemical reactions. Various scientist have immensely worked on heat and mass transfer with chemical reaction. For example, Rajashekhar and Shankar (2016) investigated the study of chemical reaction effects on unsteady MHD heat and mass transfer flow past a semi-infinite vertical porous moving plate in the presence of viscous dissipation. The effect of chemical reaction on MHD flow with heat and mass transfer past a vertical porous plate in the presence of viscous dissipation were studied by Kar *et al.* (2019). A mathematical model was established by Uwanta (2012) to analyze the effect of chemical reaction and radiation on heat and mass transfer past a semi-infinite vertical plate with constant mass flux and dissipation. Uwanta and Usman (2014) performed a numerical analysis on convective heat and mass transfer flow over a vertical plate with nth order chemical reaction in a porous medium. Recently, Reddy *et al.* (2022) investigated the influence of multi slip implications on steady-state MHD fluid flow in the occurrence of Soret and Dufour through a suction/ injection over a non-Isothermal stretching surface numerically. Reddy and Lakshminarayana (2022) also researched on the

influence of radiation, chemical reaction, heat generation, and suction/injection.

According to the above mentioned literature review, most of the researchers have investigated the characteristics of suction/injection with MHD, viscous dissipation and Soret and Dufour. The purpose of the present investigation is to examine the effect of suction/injection on free convective flow past a vertical porous plate under the action of thermal radiation and chemical reaction. The governing equations of the flow are solved numerically using implicit finite difference method of Crank-Nicholson type to obtain the momentum and energy balance equations. Results are graphically displayed and discussed for various flow parameters embedded in the problem.

2.0 MATHEMATICAL MODEL

Consider a free-convective unsteady flow of a viscous incompressible and chemically reacting fluid with radiative heat in a vertical porous channel. Fluid is assumed to be injected through one plate and simultaneously removed from the other plate V_0 . The x' - axis is taken to be along the plate in the upward direction, being the direction of the flow and the y' - axis is taken normal to the plate. The radiative heat flux in the x' - direction is considered negligible in comparison with that in the y' - direction. Sparrow and Cess (1978).

Under these assumptions, along with the Boussinesq approximation and Roseland approximation, Sparrow *et al.* (2015). The momentum, energy, and diffusion equations in dimensionless form are:

$$\frac{\partial u'}{\partial t'} + V_0 \frac{\partial u'}{\partial y'} = \nu \frac{\partial^2 u'}{\partial y'^2} + g\beta(T' - T_0) + g\beta(C' - C_0) \quad (1)$$

$$\frac{\partial T'}{\partial t'} + V_0 \frac{\partial T'}{\partial y'} = \alpha \frac{\partial^2 T'}{\partial y'^2} - \frac{\alpha}{K} \frac{\partial q_r}{\partial y'} \quad (2)$$

$$\frac{\partial C'}{\partial t'} + V_0 \frac{\partial C'}{\partial y'} = D_T \frac{\partial^2 C'}{\partial y'^2} - R^*(C' - C_0) \quad (3)$$

The initial and boundary conditions for the present problem are:

$$t' \leq 0: u' = 0, T' = T_0, C' = C_0, \quad 0 \leq y' \leq H$$

$$t' > 0: \left\{ \begin{array}{l} u' = 0, T' = T_w, C' = C_w \text{ at } y' = 0 \\ u' = 0, T' = T_0, C' = C_0 \text{ at } y' = H \end{array} \right\} \quad (4)$$

Introducing the following dimensionless quantities:

$$\begin{aligned}
 y &= \frac{y'}{H}, \quad t = \frac{t' \nu}{H^2}, \quad g = \frac{H V_0}{\nu}, \quad \theta = \frac{T' - T_0}{T_w - T_0}, \\
 \text{Pr} &= \frac{\nu}{\alpha}, \quad u = \frac{u'}{U_0}, \quad \text{Sc} = \frac{\nu}{D_r}, \quad c = \frac{C' - C_0}{C_w - C_0}, \\
 U_0 &= \frac{g \beta H^2 (T_w - T_0)}{\nu}, \quad N = \frac{g \beta H^2 (C_w - C_0)}{\nu}, \\
 R &= \frac{4 \sigma (T_w - T_0)^3}{k K}, \quad K_r = \frac{R^* H^2}{U_0}
 \end{aligned} \tag{5}$$

Substituting equation (5) into equations (1-4), the dimensionless momentum, energy, and diffusion equations are:

$$\frac{\partial u}{\partial t} + g \frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} + C_f \theta + NC \tag{6}$$

$$\frac{\partial \theta}{\partial t} + g \frac{\partial \theta}{\partial y} = \frac{1}{\text{Pr}} \left(1 + \frac{4}{3F} \right) \frac{\partial^2 \theta}{\partial y^2} - \frac{R}{\text{Pr}} \theta \tag{7}$$

$$\frac{\partial C}{\partial t} + g \frac{\partial C}{\partial y} = \frac{1}{\text{Sc}} \frac{\partial^2 C}{\partial y^2} - KrC \tag{8}$$

The initial and boundary conditions are:

$$\begin{aligned}
 t \leq 0: & \quad u = 0, \quad \theta = 0, \quad C = 0, \quad \text{for all } y \\
 t > 0: & \quad \left\{ \begin{array}{l} u = 0, \quad \theta = 1, \quad C = 1, \quad \text{at } y = 0 \\ u = 0, \quad \theta = 0, \quad C = 0, \quad \text{at } y = 1 \end{array} \right\}
 \end{aligned} \tag{9}$$

where $g, N, \text{Pr}, R, Kr, C_f$ and Sc are the Suction/injection parameter, buoyancy ratio parameter, Prandtl number, Radiation parameter, Chemical reaction, Grashof's number and Schmidt's number respectively.

The physical quantities of interest in this problem are the Skin friction, the Nusselt number and the Sherwood number, which are defined as follows

$$C_f = \frac{\tau_w}{\rho U_0^2}, \quad Nu = -\frac{q_w}{\rho C_p U_0 (T_w - T_0)}, \quad Sh = \frac{C_w - C_0}{C_p U_0 (T_w - T_0)} \tag{10}$$

3.0 Numerical Solutions

The set of partial differential equations (6-8) with the boundary conditions (9) is solved numerically using implicit finite difference scheme. We used forward difference formulas for all time derivatives and approximate both the

second and first derivatives with second order central differences. The equations corresponding to the first derivative and last grid points are modified to incorporate the boundary conditions. The implicit finite difference equation corresponding to equations (6-8) is as follows:

$$\begin{aligned}
 -r_2 U_{i-1}^{(j+1)} + (1+2r_2) U_i^{(j+1)} - r_2 U_{i+1}^{(j+1)} \\
 = (1+gr_1) U_i^{(j)} - gr_1 U_{i+1}^{(j)} + \Delta t C_f \theta_i^{(j)} + \Delta t NC_i^{(j)}
 \end{aligned} \tag{11}$$

$$\begin{aligned}
 & -qr_2\theta_{i-1}^{(j+1)} + (1+2qr_2)\theta_i^{(j+1)} - qr_2\theta_{i+1}^{(j+1)} \\
 & = (1+gr_1)\theta_i^{(j)} - gr_1\theta_{i+1}^{(j)} - \Delta tw\theta_i^{(j)}
 \end{aligned} \tag{12}$$

$$\begin{aligned}
 & -\frac{r_2}{Sc}C_{i-1}^{(j+1)} + (1+\frac{2r_2}{Sc})C_i^{(j+1)} - \frac{r_2}{Sc}C_{i+1}^{(j+1)} \\
 & = (1+gr_1 - \Delta tKr)C_i^{(j)} - gr_1C_{i+1}^{(j)}
 \end{aligned} \tag{13}$$

where $r_1 = \frac{\Delta t}{\Delta y}$, $r_2 = \frac{\Delta t}{(\Delta y)^2}$, $q = \frac{1}{Pr} \left(1 + \frac{4}{3R} \right)$, $w = \frac{R}{Pr}$.

4.0 RESULTS AND DISCUSSION

In order to point out the effects of various parameters on the flow characteristics, the following discussion is set out. The values of Pr are chosen for $Pr = 0.71, 2.0, 3.0$ and 7.0 corresponding to air, sulfur (iv) oxide, saturated liquid Freon, and water, respectively. The values of Sc considered in this study are $Sc = 0.22, 0.66, 0.94,$ and 2.62 corresponding to hydrogen, water, carbon dioxide, and propyl benzene, respectively.

Figures 1(a) and 4(b) depicts the velocity and temperature profiles for different values of dimensionless time (t). It is observed that the increase in temperature strengthens the convection current, which in turn increases both the velocity and temperature. It is also clear that both the velocity and temperature attain a steady state.

From figures 1(b) and 4(b) investigates the influence of the radiation parameter (R) on the velocity and temperature, respectively. It is observed that, as R increases, both the velocity and temperature are observed to increase. This is due to the fact that, an increase in R adds more heat to the fluid leading to an increase in temperature, which causes the velocity to increase.

Figures 2(a) and 5(b) show the effect of suction/injection parameter g on the velocity and temperature profiles, respectively. Both the velocity and temperature are seen to increase with an increase in g for ($g > 0$) while the reverse case is observed for ($g < 0$). This is as a result of heated fluid particles being introduced

in to the channel by injection through the plate at $y = 0$ while cold fluid particles are removed from the channel by suction through the plate $y = 1$ in the case of ($g > 0$). This increases the temperature thus strengthening the convection current in the channel, which in turn increases the velocity (Jha *et al.* 2015). However, the reverse trend is observed from figure 6(a). An increase in suction/injection parameter g , causes a reduction in the concentration profiles. This is due to the fact that suction/injection decelerates fluid particles through porous media, which stabilized the boundary layer growth.

Figures 2(b) and 5(a) illustrates the effects of temperature difference parameter Cf on the velocity and temperature profiles, respectively. It is observed that as the value of Cf is increased, there is a corresponding increase in the velocity of the fluid as shown in figure 2(b). A reverse trend is in figure 5(a). From this figure, it is observed that the temperature decreases with the increase in Cf .

Figure 3(a) display the effect of Pr on the velocity profiles. It is clear that the velocity decreases as the Prandtl number increases. Physically, this is possible because fluids with high Pr number have greater viscosity, which makes the fluid thick and hence move slowly.

Figures 6 and 7 depict the concentration profiles with the variations in suction/injection parameter, chemical reaction parameter, Schmidt's number, and buoyancy parameter. From these figures, it is clearly seen that the concentration decrease with the increase in $g, Kr, Sc,$ and N .

Figure 3(b) presents the effects of buoyancy ratio parameter on the velocity profiles. It is noticed that the velocity increases with the increase in N . It is due to the fact that increase in the buoyancy parameter has the tendency to increase the thermal and mass buoyancy effect. This gives rise to an increase in the induced flow.

Figures 8 and 9 illustrate the effects of R , C_f and Sh on skin-friction, rate of heat transfer in terms of Nusselt number and rate of mass transfer in terms of Sherwood number, respectively. It can be seen from figure 8 that an increase in R and C_f increases the skin-friction and Nusselt number. Whereas it shows reverse effect in the case of Sherwood number and Sc as shown in figure 9.

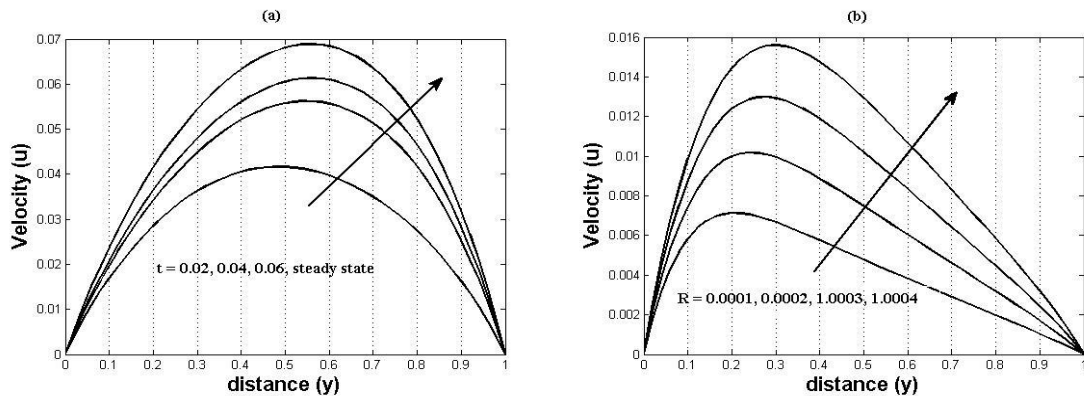


Figure 1: Velocity profile for different values of t and R for fixed values of $C_f = 5$, $g = 4$, $Pr = 0.71$, $Sc = 0.22$, $Kr = 1$ and $N = 1$.

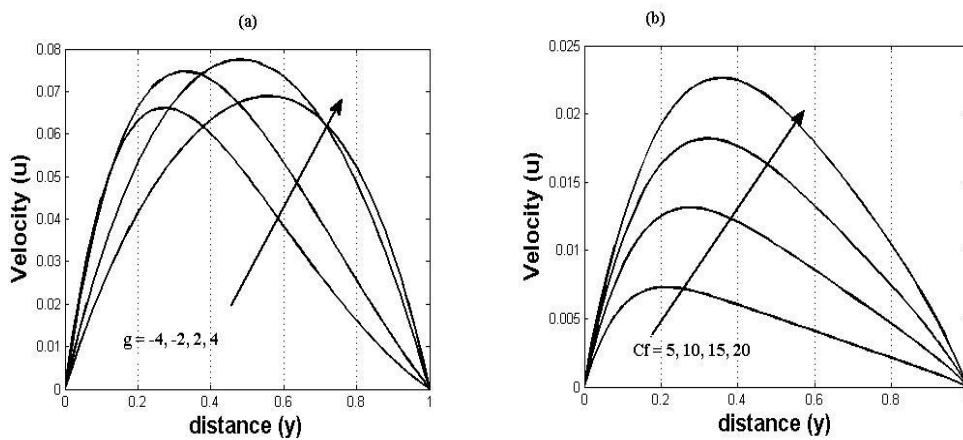


Figure 2: Velocity profile for different values of g and C_f and for fixed values of $R = 0.0001$, $t = 0.002$, $Pr = 0.71$, $Sc = 0.22$, $Kr = 1$ and $N = 1$.

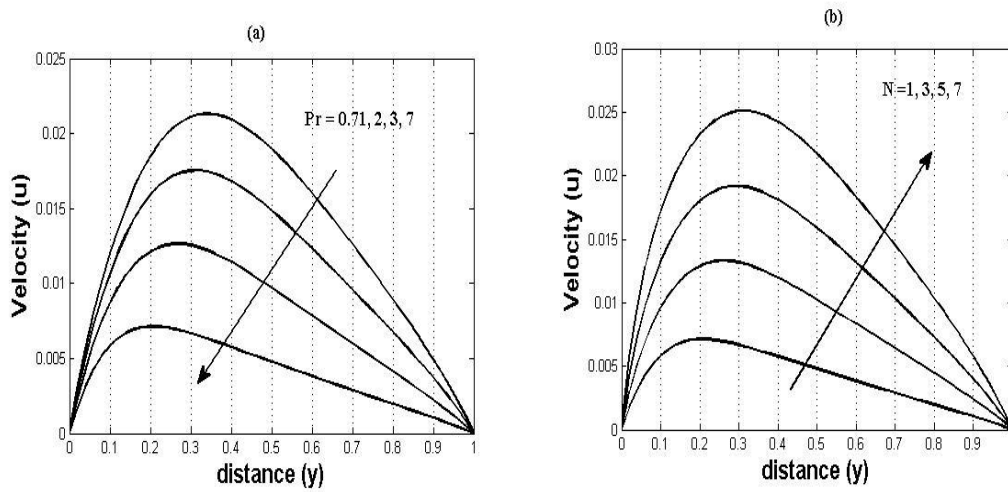


Figure 3: Velocity profiles for different values of Pr and N and for fixed values of $C_f = 5$, $g = 4$, $Sc = 0.22$, $Kr = 1$, $R = 0.0001$, $t = 0.002$.

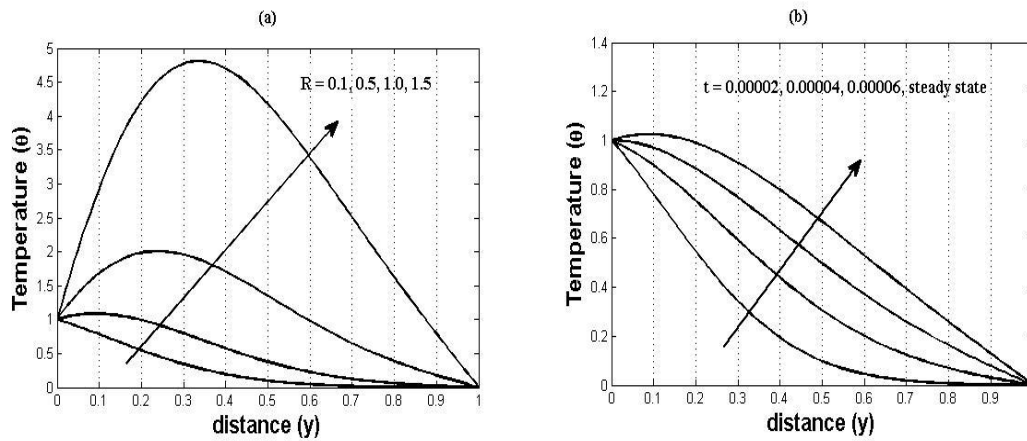


Figure 4: Temperature profiles for different values of R and t and for fixed values of $C_f = 5$, $g = 4$, $Sc = 0.22$, $Kr = 1$, $Pr = 7.0$ and $N = 1$.

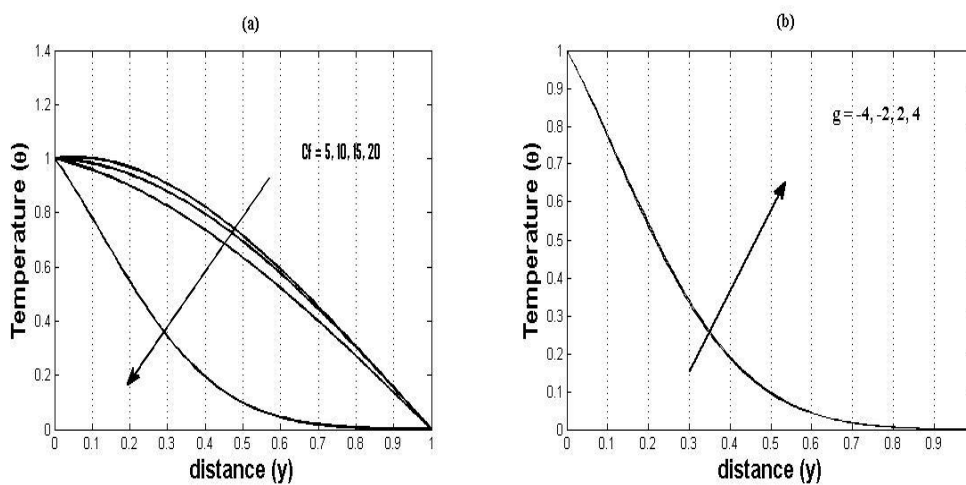


Figure 5: Temperature profiles for different values of C_f and g and for fixed values of $R = 0.1$, $t = 0.00002$, $Pr = 7.0$, $Sc = 0.22$, $Kr = 1$ and $N = 1$.

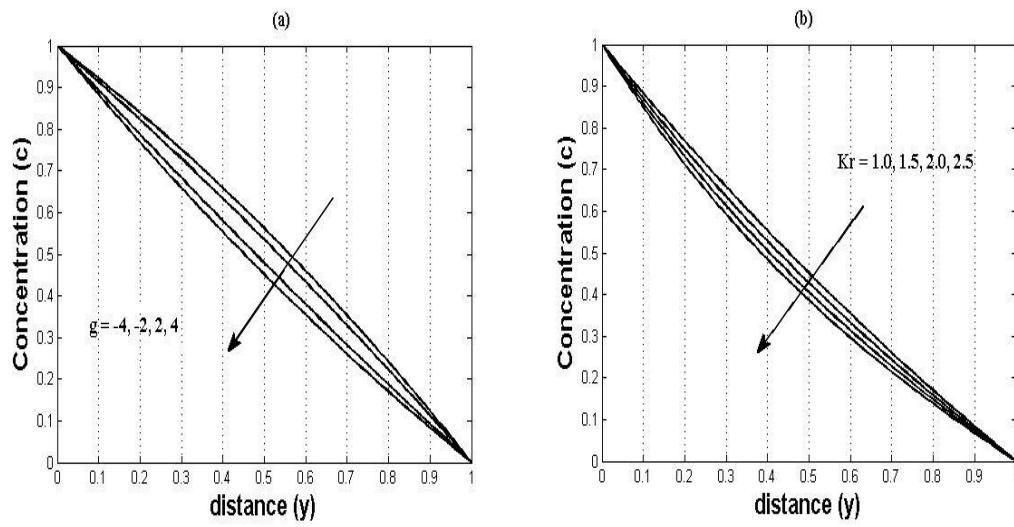


Figure 6: Concentration profiles for different values of g and Kr and for fixed values of $R = 0.0001$, $t = 0.2$, $Pr = 0.71$, $Sc = 0.22, Cf = 5$, and $N = 1$.

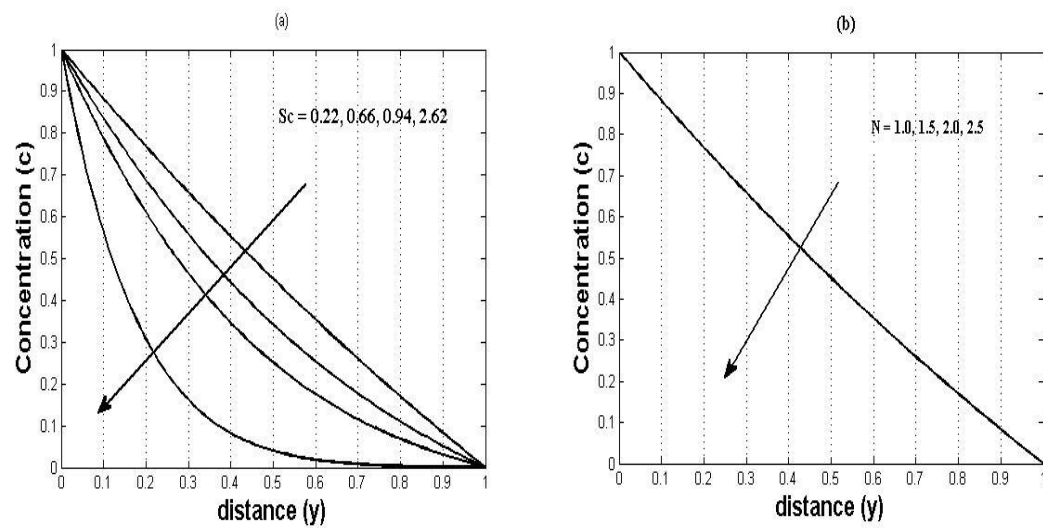


Figure 7: Concentration profiles for different values of Sc and N and for fixed values of $R = 0.0001$, $t = 0.2$, $Pr = 0.71$, $Kr = 1$, $Cf = 5$, and $g = 4$.

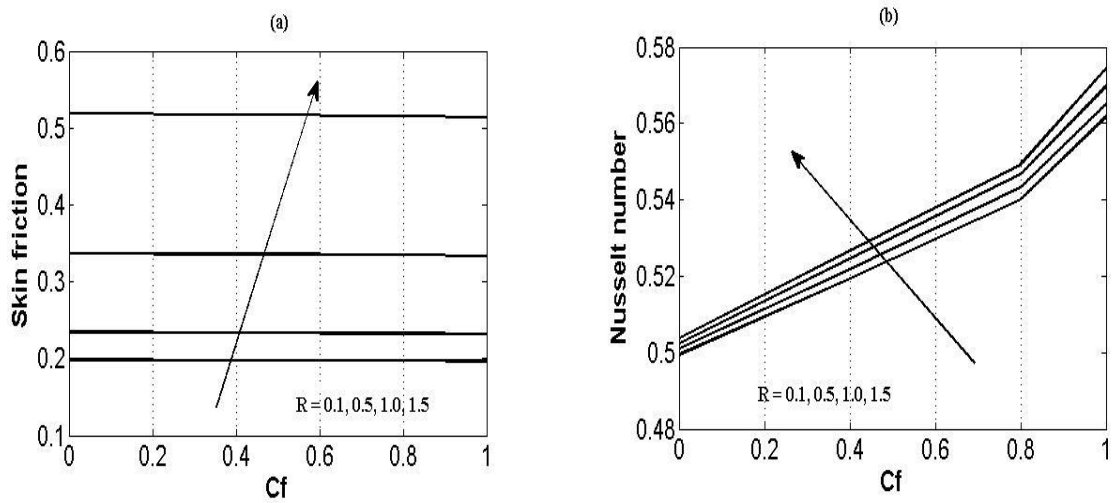


Figure 8: Effects of R on the skin-friction and Nusselt number for fixed values of $Pr = 0.71$, $Sc = 0.22$, $Kr = 1$, $N = 1$, $t = 0.002$, and $g = 4$.

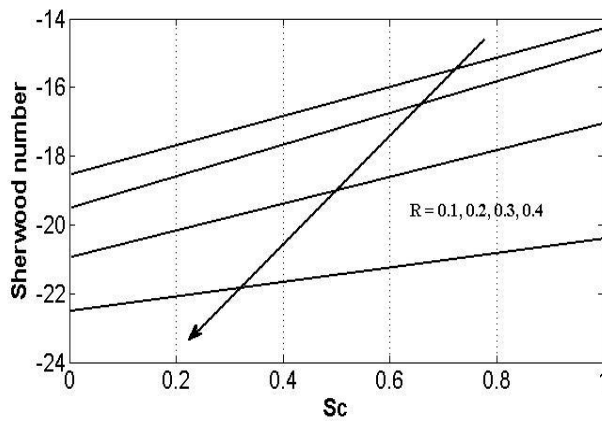


Figure 9: Effects of R on Sherwood number for fixed values of $t = 0.2$, $Pr = 0.71$, $Kr = 1$, $g = 4$, $Cf = 5$, and $N = 1$.

5.0 CONCLUSION

In this paper, the effects of suction/injection on free convective radiative flow in a vertical porous channel with mass transfer and chemical reaction has been investigated. The velocity, temperature, and concentration are obtained numerically by implicit finite difference technique. The skin-friction, rate of heat transfer in terms of Nusselt number, and rate of mass transfer in terms of Sherwood number are derived from the velocity, temperature, and concentration, respectively. The following conclusions are made;

- i. Velocity and temperature increase with time and finally reach a steady state value.
- ii. Skin-friction and rate of heat transfer increase with increase in radiation parameter and it shows reverse effect in the case of Sherwood number.
- iii. Velocity and temperature profiles increase with an increase in suction/injection parameter.
- iv. Concentration decrease with an increase in chemical reaction parameter and suction/injection parameter.
- v. Velocity increase with increase in temperature difference parameter and it

shows reverse effect in the case of temperature.

NOTATIONS

C - concentration

D_T - coefficient of temperature diffusivity

R - Radiation parameter

Sk - Skin-friction

N - buoyancy ratio parameter

Nu - Nusselt number

Pr - Prandtl number

Sc - Schmidt number

Kr - Chemical reaction parameter

Sh - Sherwood number

T - temperature

u, v - velocities in the x - and y - direction

respectively

x, y - Cartesian coordinates along the plate and

normal to it, respectively

t - dimensionless time

R^* - dimensional chemical reaction parameter

T_∞' - temperature of the fluid away from the plate

T_ω' - plate temperature

Greek Letters

b^* - coefficient of expansion with concentration

b - coefficient of thermal expansion

ρ - density of fluid

S - electric conductivity

θ - dimensionless temperature

ν - kinematic viscosity

g - suction/injection parameter

Cf - Temperature difference parameter

Subscripts

w - condition at wall

∞ - condition at infinity

REFERENCES

- Fahad, A. M., Abdelhalim, E. and Khaled, S. M. (2017). Effects of suction/injection and radiation on the MHD Marangoni convection boundary layer heat and mass transfer with joule heating and viscous dissipation. *Advances and Applications in Fluid Mechanics*, 20(1), 199-209.
- Jha, B.K., Isah, B.Y. and Uwanta, I.J. (2015). Unsteady mhd free convective coquette flow between vertical porous plates with thermal radiation. *Journal of King Saud University, Science*, 06(005): 1-13.
- Kandasamy, R., Loganathan, P. and Ganesan, P. (2007). Heat and mass transfer along a wedge with variable surface tension and heat radiation in the presence of suction or injection. *Journal of Heat and mass Transfer*, 2007.
- Kar, S. Senapti, N. and Swain, B. (2019). Effect of chemical reaction on MHD flow with heat and mass transfer past a vertical porous plate in the presence of viscous dissipation. *International Journal of Advances in Applied Science*, 8(1):83-94.
- Ogulu, A. and Makinde, O. D. (2008). Unsteady hydromagnetic free convection flow of a dissipative and radiating fluid past a vertical plate with constant heat flux. *Chemical Engineering Communications*, 196(4).
- Pathak, G. and Maheshwari (2006). Effect of radiation on unsteady free convection flow bounded by an oscillating plate with variable wall temperature. *International Journal of Applied Mechanics and Engineering*, 11(2), 371-382.
- Prasad, K., Vaidia, H., Makinde, O., Vajravelu, K. and Valmiki, R. (2020). Impact of suction/injection and heat transfer on unsteady MHD flow over a stretchable rotating disc. *Latin American Applied Research*, 50(3):159-165.
- Rajashekhar, M. N. and Shankar, G. (2016). Study of chemical reaction effects on unsteady MHD heat and mass transfer flow past a semi-infinite vertical porous moving plate in the presence of viscous dissipation. *International Journal of Engineering Trends and Technology*, 42(8):1-15.
- Reddy, N. N., Reddy, Y. D., Rao, V. S., Goud, B. S., and Nisar, K. S. (2022). Multiple slip effects on steady MHD flow past a non-isothermal stretching surface in presence of Soret, Dufour with suction/injection. *International Communications in Heat and Mass Transfer*, 134. doi.org/10.1016/j.icheatmasstransfer.2022.106024.
- Reddy, M. V., and Lakshminarayana, P. (2022). MHD radiative flow of Williamson nanofluid with Cattaneo-Christov model over a stretching sheet through a porous medium in the presence of chemical reaction and

- suction/injection. *Journal of Porous Media*, 25. doi.org/10.1615/JPorMedia.2022041423.
- Rehman, S., Idrees, M., Shah, R. A. and Khan, Z. (2019). Suction/injection effects on an unsteady MHD Casson thin film flow with slip and uniform thickness over a stretching sheet along variable flow properties. *Boundary Value problems*, 26:1-24
- Shateyi, S. (2008). Thermal radiation and buoyancy effects on heat and mass transfer over a semi-infinite stretching surface with suction and blowing. *Journal of Applied Maths*, Article ID 414830, 12 pgs.
- Sparrow, E. M. and Cess, R. D. (1978). *Radiation Heat Transfer*, Augmented edition, Hemisphere Publ. Corp., Washington, D. C., Chapters 7 and 10.
- Sparrow, E. M., Eckert, E. R. and Munkowyz, W. J. (1962). Transpiration cooling in a magneto hydrodynamic stagnation point flow. *Applied Science Research A*, 11, 125-147.
- Suneetha, S., Reddy, N. B. and Prasad, V. R. (2008). Thermal radiation effects on MHD free convection flow past an impulsively started vertical plate with variable surface temperature and concentration. *Journal of Naval Architecture and Marine Engineering*, 5(2), 57-70.
- Usman, H. Fazle, M. and Giulio, L. (2016). Heat and mass transfer along vertical channel in porous medium with radiation effect and slip condition. *International Journal of Heat and Technology*, 34(1):129-136.
- Uwanta, I.J. and Usman, H. (2014). On the influence of Soret and Dufour effects on MHD free convective heat and mass transfer flow over a vertical channel with constant suction and viscous Dissipation. *Hindawi Publishing Cooperation, International scholarly Research Notices*, 3:1-11.
- Uwanta, I. J. (2012). Effect of chemical reaction and radiation on heat and mass transfer past a semi-infinite vertical plate with constant mass flux and dissipation. *European Journal of Scientific Research*, 87(2):90-200.
- Uwanta, I. J. and Usman, H. (2014). Convective heat and mass transfer flow over a vertical plate with nth order chemical reaction in a porous medium. *International Journal of Scientific Engineering and Technology*, 3(2): 172-185