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Original Research Article

Effects of Injection/Suction on Unsteady MHD Natural Convective Radiative Flow of Heat Mass Transfer in a Plumb Frequency

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Abstract

This paper explores the effects of injection/suction on MHD unsteady natural convective radiative flow of heat mass transfer in a plumb frequency. The governing partial differential equations are converted to non- dimensional forms and solved numerically by an efficient, implicit, iterative method of Crank Nicolson. Suction/injection is used to control the fluid flow in the channel, and an exothermic chemical reaction of Arrhenius kinetic is considered. A parametric study illustrating the influence of various physical parameters is performed. Numerical results for the velocity, temperature, ad concentration as well as the skin friction factor, surface heat and mass transfer rates have been presented for parametric variations of injection/suction, Grashof number, MHD, Prandtl number and Schmidt number. It is reported that the velocity profile increase as thermal grashof number increases. The temperature profile rises by the influence in increasing values of injection and decreases by increasing values of suction parameter. While concentration profile decreases by the increasing values of chemical reaction in the case of suction and injection. The dependence of the skin friction coefficient, rate of heat transfer and mass transfer on these parameters has been discussed.

Keywords: Radiative flow, Suction/Injection, MHD, Unsteady, Heat transfer, Mass transfer.

INTRODUCTION

Suction/injection method was first introduced by L. Prandtl in 1904 as one of the means for preventing or delaying boundary layer separation. Suction/injection is one of the methods of boundary layer control, which have the aim of reducing losses of energy in channels. The study of injection/suction on the boundary layer control played an important role in the field of aerodynamics and space sciences. Shojaefard *et al*. [17] studied suction/injection to control fluid flow on the surface of subsonic aircraft. By controlling the flow as such, fuel consumption might be decreased by 30%; a considerable reduction in pollutant emission is achieved. In mass transfer cooling, suction/injection of a fluid through the bounding significantly change the flow field and as a result, affect the heat transfer rate from the plate; studied by Ishak *et al*., [6]. Many interests have been built in the study of flow of heat and mass transfer with suction/injection because of its extensive engineering applications.

Injection is defined as the administering a fluid in to a system as in the case of blood transfusion while in the case of suction is defined as the exclusion of fluid from a system. If the two runs at the same time, then the opposite sides of the plates are porous which allow the fluid to move in and out. Suction/injection of fluid channels has gained a special concerned due to its paramount applications of different field such as Science, engineering, petroleum drilling industries and food processing industries etc. The effects of suction/injection on a steady mixed convection flow through a vertical channel were investigated by Jha and Aina [8]. A transient case of hydro magnetic-free convection flow in the presence of suction/injection and found that fluid velocity decreases with increases of suction/injection were studied by Jha *et al*. [9] Heat transfer is a branch of thermal engineering that deals with the rate of transfer of thermal energy (heat) between physical systems due to temperature difference. Suction/injection is a mechanical effect and used to control the energy losses in the boundary layer region by reducing the drag force on the surface. Uwanta and Hamza, [19] studied the effect of suction /injection on unsteady hydro magnetic natural convection flow of viscous reactive fluid between vertical porous plates in the presence of thermal diffusion.

Suction/injection is the study of controlling the fluid flow in the channel, and an exothermic chemical reaction of Arrhenius kinetic is considered. Jha *et* al. [7] investigated the combined effect of suction / injection on MHD free - convection flow in a vertical channel with thermal radiation . Uwanta and Usman [21] studied the finite difference solutions of magneto hydrodynamic free convective flow with constant suction and variable thermal conductivity in a Darcy-Forchheimer porous medium. Rehman *et al*. [14] investigated suction/injection effects on an unsteady MHD casson thin film flow with slip and uniform thickness over a stretching sheet along variable flow properties. Parasad *et al*. [12] examined the impact of suction/injection and heat transfer on unsteady MHD flow over stretchable rotation disk. In achieving this it examined the unsteady magneto hydro-dynamic two- dimensional boundary layer flow and heat transfer over a stretchable rotating disk with mass suction/injection is investigated. Lavanya and Ratmann [11] have obtained the analytical solution by taking the effect of radiation and mass transfer on unsteady MHD natural convective flow past a vertical porous plate embedded in a porous medium in a slip flow regime with heat source / sink and soret effect. Bhattacharya [4] analyzed the effects of heat source/sink on MHD flow and heat transfer over a shrinking sheet with mass suction.

Hsiao [5] studied the heat and mass transfer of a steady laminar boundary-layer flow of a viscous flow past a nonlinearly stretching sheet with radiation and heat dissipation effects. The study of variable thermal conductivity on heat and mass transfer flow over a vertical channel with magnetic field intensity was investigated by Uwanta and Usman [20] Sree and Alam [18] studied the effect of variable viscosity and thermal conductivity on MHD free convection flow over an isothermal vertical plate immersed in a fluid with heat conduction. Amos *et al.* [2] investigated the effects of chemically reacting MHD free convective heat and mass transfer flow of dissipative casson fluid with variable viscosity and thermal conductivity. Abiodun and Kabir [1] analyzed the combine effects of variable viscosity and thermal conductivity on fluid flow and thermodynamic in a vertical channel. Sarojamma *et al.* [15] investigated the influence of thermal radiation paired with variable thermal conductivity on MHD Micropolar fluid flow over an upper surface. They also considered the fluid flow along an upper horizontal surface of a paraboloid of revolution with porous medium. Kareem and Salawu [10] examined the effects on variable thermal conductivity and viscosity in a dissipative heat and mass transfer of an inclined magnetic field in a permeable medium past a continuously stretching surface for power-law difference in the temperature and concentration.

Quader and Mahmud Alam [13] investigated unsteady MHD free convective heat and mass transfer flow through a semi-infinite vertical porous plate in a rotating system with the combined soret and dufour effects in the presence of Hall current and constant heat flux. It is considered that the porous plate is subjected to constant heat flux. Seddek *et al.* [16] have investigated the effects of temperature dependent viscosity and thermal conductivity on unsteady MHD convective heat transfer past a semi- infinite vertical porous plate in the presence of suction and magnetic field parameter. Babu *et al.* [3] have studied the effects of radiation and heat source/sink on the steady of two dimensional magneto hydrodynamic (MHD) boundary layer flow past a shrink sheet with wall mass suction by numerical technique. The aim of the present research is to study the effects of injection/suction on unsteady natural convective radiative flow of heat mass transfer in a plumb frequency. In this study, an exothermic chemical reaction of Arrhenius kinetics is considered and injection/suction is used to control the fluid flow in the channel.

MATHEMATICAL FORMULATION

The following assumptions have been made,

1. Consider the unsteady radiative flow of viscous incompressible fluid past a vertical channel with suction/injection and magnetic field intensity.
2. A magnetic field B_0 of uniform strength is applied transversely to the direction of the flow.
3. The *x-axis* taken along the plate in the vertically upward direction
   The *y- axis* is normal to the plate in the direction of the applied magnetic field.
5. The viscous dissipation in the energy equation have been assumed for higher speed flow as well as heat source for heat generation.
6. The suction is assumed in all the three equations and soret is only assumed in the concentration equation for observing their effects on the flow.
7. The magnetic Reynolds number is assumed to be very small and hence the induced magnetic field is in comparison with the applied magnetic field in the absence of any input electric field.
8. Since the plate is infinite and the fluid motion is unsteady so all the flow variables depend only on *y* and time (*t*).

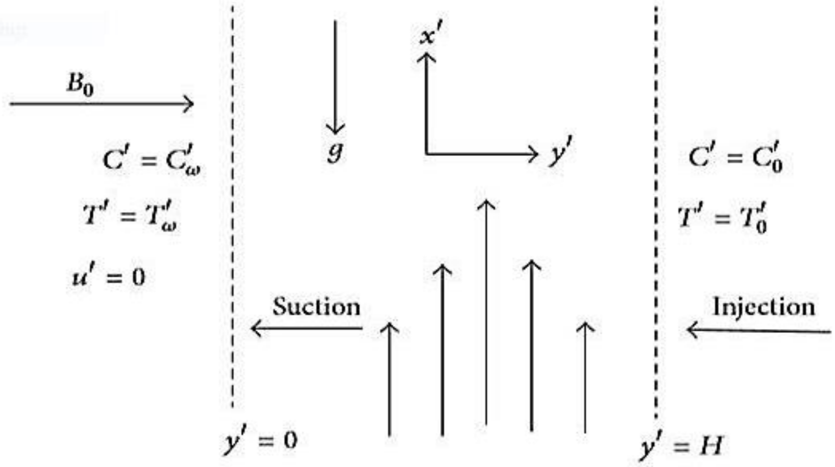

Figure 1: Coordinate System for the Physical Model of the Problem

Then, the fully developed is governed by the following set of equations

$$\frac{\partial u'}{\partial t'} + v\frac{\partial u'}{\partial y'} = v\frac{\partial^2 u'}{\partial y^2} - \frac{\sigma\beta_0^2 u'}{\rho} - \frac{v}{k^*}u' + g\beta\left(T' - T_0'\right) + g\beta^*\left(C' - C_0'\right) \quad (1)$$

$$\frac{\partial T'}{\partial t'} + v\frac{\partial T'}{\partial y'} = \frac{k_0}{\rho Cp}\frac{\partial}{\partial y'}\left[1 + \alpha\left(T' - T_0'\right)\frac{\partial T'}{\partial y'}\right] - \frac{1}{\rho Cp}\frac{\partial q_r}{\partial y'} \quad (2)$$

$$\frac{\partial c'}{\partial t'} + v\frac{\partial c'}{\partial y'} = D\frac{\partial^2 c'}{\partial y^2} - R^*\left(C' - C_0'\right) \quad (3)$$

With corresponding boundary conditions,

$$\begin{aligned} &t \le 0, u = 0, \theta = C = 0 \quad for \ \ all \ \ y \\ &t > 0, u = 0, \theta = 1, C = 1 \quad at \quad y = 0 \\ &u = 0, \theta = 0, C = 0 \quad at \quad y = 1 \end{aligned} \quad (4)$$

To acquire the solutions of equations (1), (2) and (3) subject to the boundary conditions (4) in non-dimensional form, we introduce the following non-dimensional quantities:

$$\begin{aligned} &u = \frac{u'}{u_0},\ t = \frac{t' u_0}{H^2},\ y = \frac{y'}{H},\ \theta = \frac{T' - T_0'}{T_w' - T_0'} \\ &C = \frac{C' - C_0'}{C_W' - C_0'},\ \Pr = \frac{u_0 \rho C_p}{k_0},\ M = \frac{\sigma\beta_0 H^2}{\rho u_0}. \\ &Sc = \frac{u_0}{D},\ k = \frac{k u_0}{v H^2},\ K_r = \frac{R^\bullet H^2}{u_0}. \\ &\lambda = \alpha\left(T' - T_0'\right),\ R = \frac{16 a \sigma_0 H T_0'^3}{k u_0^2}. \\ &Gr = \frac{H^2 g\beta\left(T_w' - T_0'\right)}{u_0^2}. \end{aligned} \quad (5)$$

$$Gc = \frac{H^2 g \beta^{\bullet}\left(C'_w - C'_0\right)}{u_0^2}. \quad V = \frac{v}{u_0},$$

The skin-friction coefficient, Nusselt number and Sherwood number are the important physical parameters for this type of boundary layer flow, which in non- dimensional form respectively are given by:

$$C_f = \left(\frac{\partial u}{\partial y}\right)_{y=0}, \quad Nu = -\left(\frac{\partial \theta}{\partial y}\right)_{y=0}, \quad Sh = \left(\frac{\partial C}{\partial y}\right)_{y=0} \tag{6}$$

The non-dimensional quantities reduce to the following:

(i) $$\frac{du}{dt} + V\frac{du}{dy} = \frac{d^2u}{dy^2} - \left(m + \frac{1}{k}\right)u + Gr\theta + GcC \tag{7}$$

(ii) $$\Pr\frac{d\theta}{dt} + \Pr V\frac{d\theta}{dy} = \left(1 + \lambda\theta\right)\frac{d^2\theta}{dy^2} + \lambda\left(\frac{d\theta}{dy}\right)^2 - R\theta \tag{8}$$

(iii) $$Sc\frac{dC}{dt} + ScV\frac{dC}{dy} = \frac{d^2C}{dy^2} - ScKrC \tag{9}$$

The initial and boundary conditions in non-dimensional quantities are:

$$\begin{aligned} &t \le 0, u = 0, \theta = C = 0 \quad for \;\; all \;\; y \\ &t > 0, u = 0, \theta = 1, C = 1 \quad at \quad y = 0 \\ &u = 0, \theta = 0, C = 0 \quad at \quad y = 1 \end{aligned} \tag{10}$$

NUMERICAL SOLUTION PROCEDURE

To solve the unsteady non- linear coupled partial differential equations (7) - (9) with the agreeing initial and boundary conditions (10), an implicit finite difference technique of Crank-Nicolson type has been engaged. The finite difference equations equivalent to equations (7)-(9) using the method are as follows:

$$\frac{u_i^{j+1} - u_i^j}{\Delta t} + V\left(\frac{u_{i+1}^j - u_i^j}{\Delta y}\right) = \frac{1}{(\Delta y)^2}\left(u_{i+1}^{j+1} - 2u_i^{j+1} + u_{i-1}^{j+1}\right) - Mu_i^j - \frac{1}{k}u_i^j + Gr\theta_i^j + GcC_i^j \tag{11}$$

$$\Pr\left(\frac{\theta_i^{j+1} - \theta_i^j}{\Delta t}\right) + \Pr V\left(\frac{\theta_{i+1}^j - \theta_i^j}{\Delta y}\right) = \frac{\left(1 + \lambda\theta_i^j\right)}{(\Delta y)^2}\left(\theta_{i+1}^{j+1} - 2\theta_i^{j+1} + \theta_{i-1}^{j+1}\right) + \lambda\left(\theta_{i+1}^j - \theta_i^j\right)^2 - R\theta_i^j \tag{12}$$

$$Sc\left(\frac{C_i^{j+1} - C_i^j}{\Delta t}\right) + ScV\left(\frac{C_{i+1}^j - C_i^j}{\Delta y}\right) = \frac{1}{(\Delta y)^2}\left(C_{i+1}^{j+1} - 2C_i^{j+1} + C_i^{j+1}\right) - ScKrC_i^j \tag{13}$$

The initial and boundary conditions may be expressed as:

$$\left.\begin{aligned} &u_{i,j} = 0, \quad \theta_{i,j} = 0, \quad C_{i,j} = 0 \\ &u_{0,j} = 0, \quad \theta_{0,j} = 1, \quad C_{0,j} = 1 \\ &u_{H,j} = 0, \quad \theta_{H,j} = 0, \quad C_{H,j} = 0 \end{aligned}\right\} \tag{14}$$

Where H correspond to 1.

Equations (10), (11) & (12) may be written respectively as follows:

$$-r_1 U_{i-1}^{j+1} + r_3 U_I^{j+1} + r_1 U_{i+1}^{j+1} = r_4 U_i^j - r_2 U_{1+1}^j + r_5 \theta_i^j + r_6 C_i^j \quad (15)$$

$$-r_3 \theta_{i-1}^{j+1} + r_{11} \theta_i^{j+1} - r_3 \theta_{i+1}^{j+1} = r_{12} \theta_i^j + r_4 \left(\theta_{i+1}^j - \theta_i^j\right)^2 \quad (16)$$

$$-r_5 C_{i-1}^{j+1} + r_{13} C_i^{j+1} - r_5 C_{i+1}^{j+1} = r_{14} C_i^j - r_2 C_{i+1}^j \quad (17)$$

The index i, is equivalent to space y and j equivalent to time t. Δy and Δt are the mesh size along y-direction and time t-direction respectively. The finite difference equations (15) - (17) at every internal nodal point on a particular n-level establish a tri-diagonal system of equations, which are solved by using the Thomas algorithm. In each time step, the temperature and concentration profile have been computed first from equations (16) & (17) and then the computed values are used to obtain the velocity profile at the end of time steps that u_{i+1} computed from equation (15). This procedure is carried out until the steady state is grasped. The steady-state solution of the convergence criteria for stability of the system is assumed to have been reached.

RESULTS AND DISCUSSION

This section, constitute the analysis of the fluid flow. Numerical computations is carried out for various values of the major parameters such as, Suction/injection Parameter, Magnetic field (M), thermal Grashof number (Gr), Solutal Grashof number (Gc), Porous parameter (K), Variable thermal conductivity parameter (λ), Radiation parameter (R), Prandtl number ($\Pr$), Schmidt number (Sc), chemical reaction (K_r) and dimensionless time (t). Therefore, this study is focused on the effects of these governing parameters on the transient velocity, temperature as well as concentration profiles.

The default values of the thermo physical parameters are specified as follows:

$$Gr = 5, Gc = 5, M = 2, \Pr = 0.71, k = 0.5$$
$$R = 5, \lambda = 0.5, Kr = 1, Sc = 0.60$$

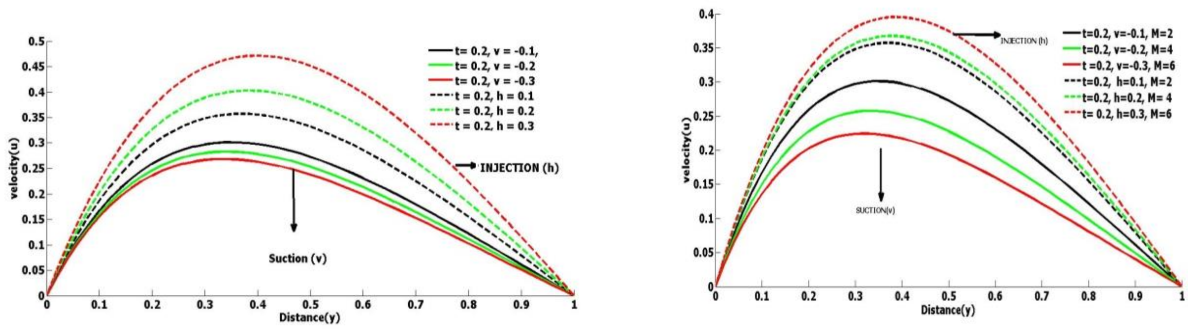

Figure 2: Velocity profile for different values of Injection or Suction (*V*) and Magnetic Field (M)

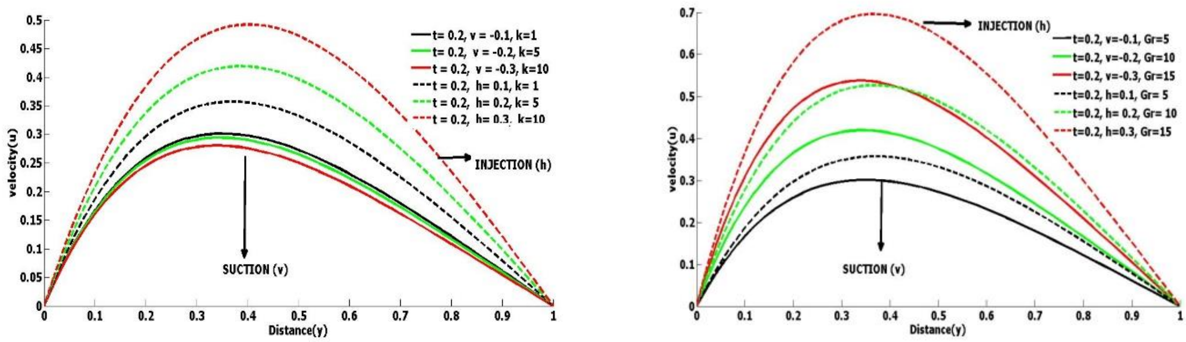

Figure 3: Velocity profile for different values of Porous (k) thermal Grashof numbers (*Gr*)

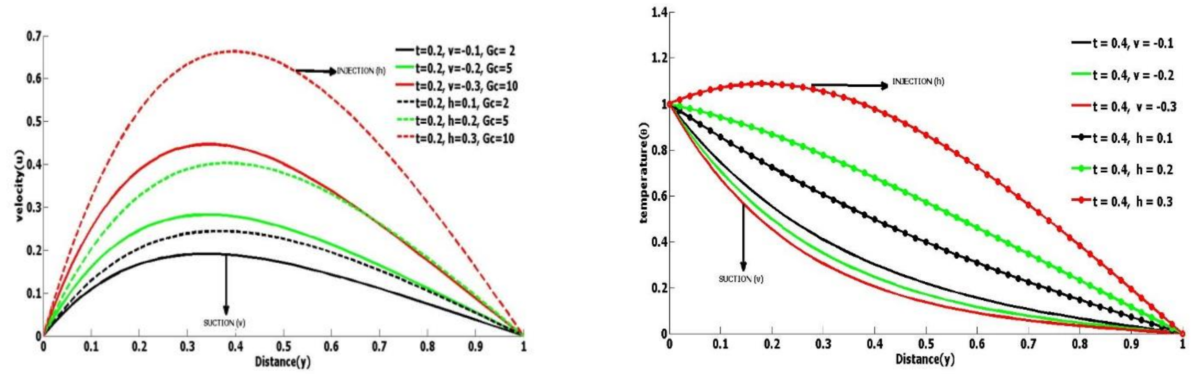

Figure 4: Velocity & Temperature profiles with different values of Solutal Grashof number and Injection or Suction (*V*)

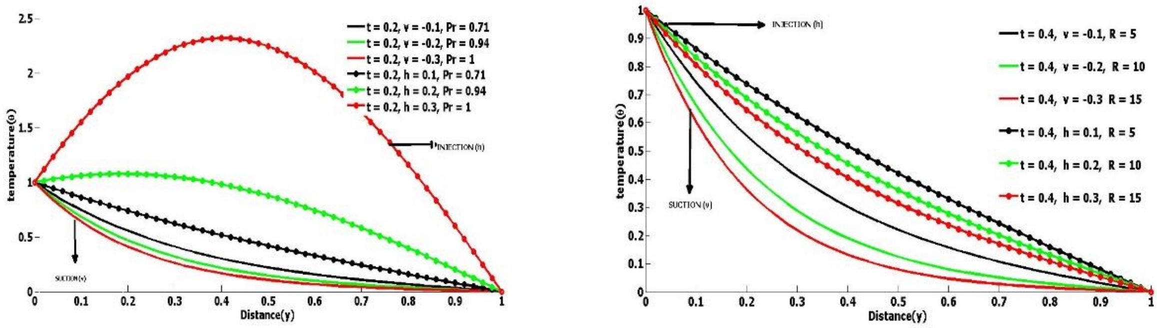

Figure 5: Temperature profiles with different values of prandtl number (Pr) and Radiation (R)

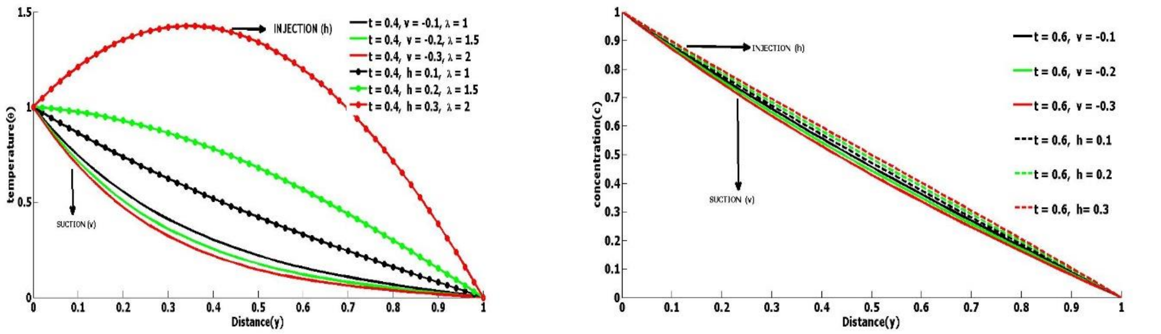

Figure 6: Temperature and Concentration profiles for different values of Variable thermal conductivity (λ) and Injection or Suction

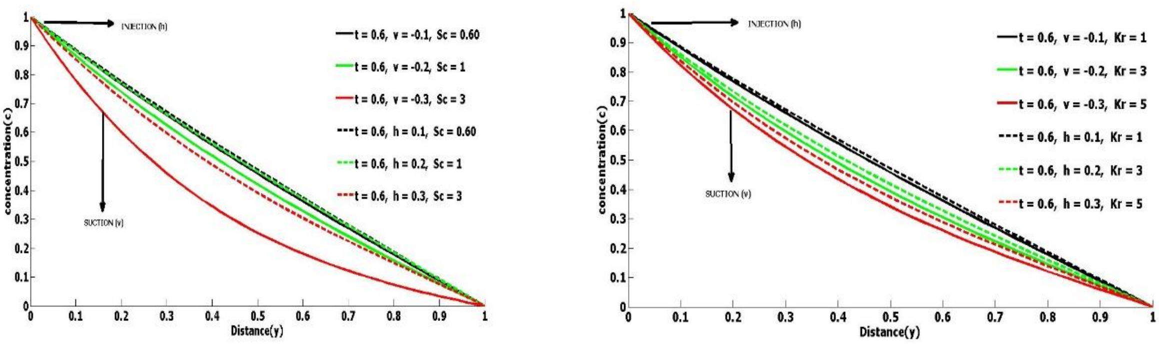

Figure 7: Concentration profiles for different values of Schmidt number (Sc) and Chemical reaction

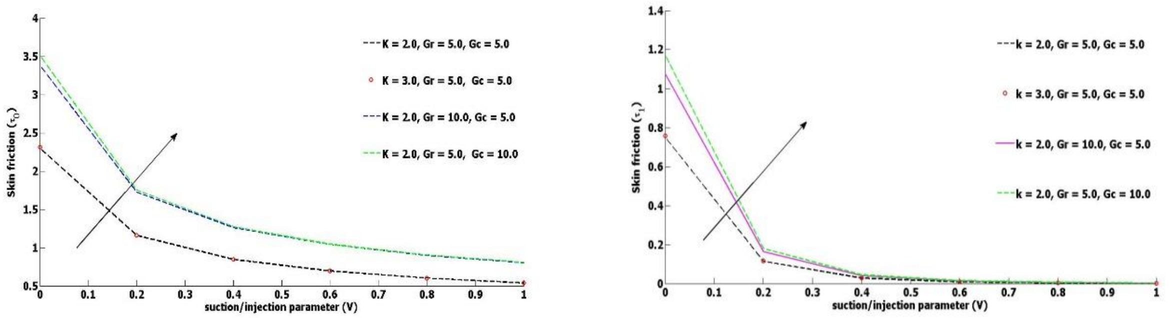

Figure 8: Effect of suction/injection (V) on skin friction with k = 2.0, Gr = 5.0, Gc = 5.0, V = 0, 0.2, 0.4, 0.6, 0.8 & 1

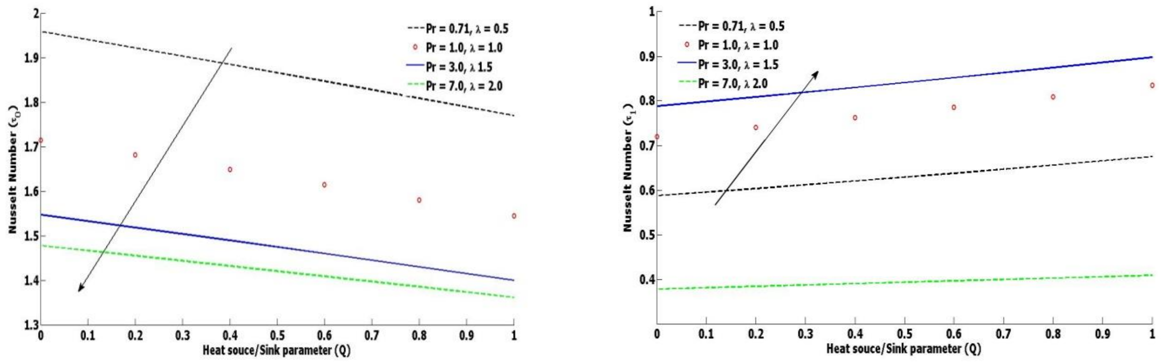

Figure 9: Effect of Suction/injection (V) on nusselt number with Pr = 0.71, Lmd = 0.5, V = 0, 0.2, 0.4, 0.6, 0.8 &1

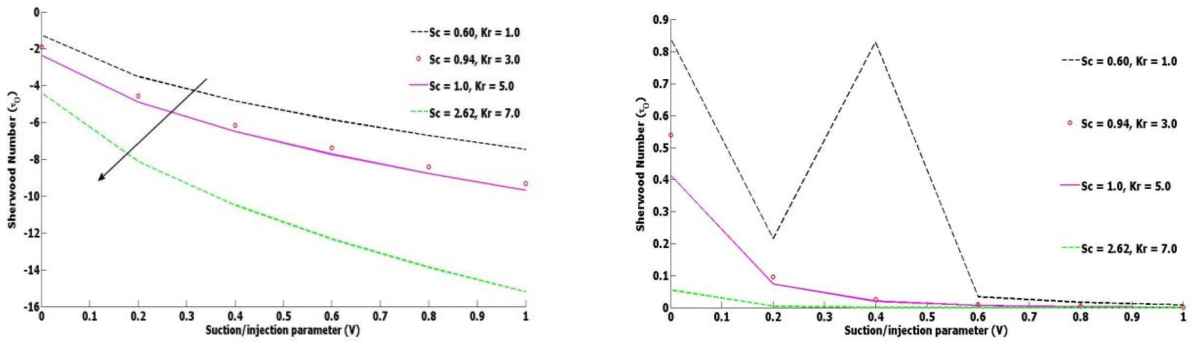

Figure 10: Effect of suction/injection (V) on sherwood number with Sc = 0.60, Kr = 1.0, V = 0, 0.2, 0.4, 0.6, 0.8 & 1

Figs. 2 & 3, revealed the velocity profiles for various values of Suction/injection (V), Magnetic field (M) and Porous (k) parameters. It is observed that, velocity curve of the equivalent boundary layer thickness decreases due to increasing values of suction and increases due to increasing values of injection for all of the above mention parameters. This is because suction/injection parameter controls the fluid flow on the channel, which as a result affect the heat transfer rate from the plate. Figs. 4&5 shows the influence of *Gr and Gc* on the velocity profiles. It is clear that the momentum boundary layer thickness increases with increasing values of *Gr and Gc*. This is as a result of thermal energy in the boundary layer. Fig. 6 depicts the effect of suction/injection (V) parameter on the temperature profile. It is noticed that the fluid temperature decreases with increasing values of suction and increases with increasing values of injection. In case of suction the fluid at ambient conditions is brought closer to the surface and reduces the thermal boundary layer thickness. The same principle used but in opposite direction in case of injection. Fig. 5 displays the effect of Prandtl number (*Pr*) over the temperature distributions. It is observed that the temperature of the fluid decreases near the heated plate with increasing values of Prandtl number in terms of suction, but increases near the cold plate in terms of injection, where it resulted in boundary layer thickness of the fluid to rise up thereby causes increase in thermodynamics. Fig.8 describes the effects of Radiation (*R*) Parameter on the temperature profile. The fluid temperature radiated as particles in the boundary layer which result to the decreasing of the fluid by the increasing values of Radiation (*R*) parameter both in terms of suction and injection.

Fig. 6 illustrate the effects of the Variable thermal conductivity (λ) parameter on the temperature distributions. It is seen that increasing values of

Variable thermal (λ) increases the temperature of the fluid in case of injection and decreases in terms of suction. Fig. 6 shows the effects of suction/injection on the concentration profiles. It is noticed that concentration of the fluid increases with increasing values of injection and decreases with increasing of suction. Fig. 7 displays the effects of Schmidt number (Sc) parameter on the concentration distributions. It is observed that increase in Schmidt number (Sc) corresponds to a weaker solute diffusivity which allows a shallower penetration of solutal effect. As a result the concentration decreases with increasing of Schmidt number (Sc). Fig. 7 shows the effects of chemical reaction (Kr) on the concentration profile. It is noticed that increasing the values of chemical reaction parameter decreases the concentration profile both in terms of suction and injection. The logic is that as chemical reaction increases, the quantity of solute molecules undergoing them to grows, this causes concentration to drop, which in turn reduces the like hood of destructive chemical reaction. Figs. 8 shows the variation of skin friction profiles with respect to porous parameter (k). Thermal grashof number (Gr), Solutal grashof number (Gc) and Suction/injection (V) parameters.It is observed the skin friction coefficient rises with increase in these parameters.

Figs. 9 illustrates the graph of Nusselt number. It is observed that Nusselt number decreases with increasing values of Prandtl number (Pr), Variable thermal conductivity (λ) and Suction/injection (V) parameters. Figs. 10 demonstrates the graph of Sherwood number and noticed that Sherwood number deceases by the increasing of Schmidt number (Sc), Chemical reaction (Kr) and Suction/injection (V).

CONCLUSIONS

The following conclusions are made from the present investigation:

1. Velocity profiles decreases with increasing values of Porous (k), Magnetic field (M) and Suction/injection parameters, while increases with increasing values of Thermal Grashof number (Gr) and Solutal Grashof number (Gc) as shown in Figs. (2-3) and Figs. (4).
2. Temperature profiles increases with increasing values of Suction/injection, Variable thermal conductivity (λ) and Prandtl number, while decreases by increasing values of Radiation (R) parameter as it is clearly indicated in Figs. 5, 6.
3. Concentration Profiles decreases with increasing values of Schmidt number (Sc), Chemical reaction (Kr) and Suction/injection parameters as this is observed in Figs. 7
4. The skin friction coefficient increases with increasing values of Porous (k), Thermal grashof number (Gr), Solutal grashof number (Gc) and Suction/injection parameters as illustrated in Figs. 8.
5. The rate of heat transfer in terms of Nusselt number falls with increase in the values of Prandtl number (Pr), Variable thermal conductivity (λ) and Suction/injection (V) parameters as it is noticed in figure 9
6. It is marked in Fig. 10 that the rate of concentration transfer decreases with increasing values of Schmidt number (Sc), Chemical reaction (Kr) and Suction/injection (V) parameters.

APPENDIX

$$p=\left(M+\frac{1}{k}\right),\ \alpha=1+\lambda\theta,\ r_1=\frac{\Delta t}{(\Delta y)^2},\ r_2=\frac{V\Delta t}{\Delta y},\quad r_3=\frac{\Delta t}{\Pr(\Delta y)^2},\quad r_4=\frac{\Delta t\lambda}{\Delta y}$$

$$r_5=\frac{\Delta t}{Sc(\Delta y)^2},\quad d_1=r_1,\ d_2=1+2r_1,\quad d_3=1+r_2-p\Delta t,\ d_4=r_2,\quad d_5=\Delta tGr,$$

$$d_6=\Delta tGc,\ d_7=r_3\alpha,\ d_8=1+2r_3\alpha,\ d_9=r_4,\ d_{10}=\left(1+r_2-\frac{\Delta tR}{\Pr}\right),\ d_{11}=r_5,$$

$$d_{12}=1+2r_5,\ d_{13}=1+r_2-\Delta tKr,\quad d_{14}=r_2.$$

NOMENCLATURE

C	Concentration
C_p	Specific heat at constant pressure
D	Mass diffusivity
g	Acceleration due to gravity
Gr	Thermal Grashof number
Gc	Solutal Grashof number
K	Porous parameter
Nu	Nusselt number
Pr	Prandtl number
Sc	Schmidt number

R Radiation parameter
Kr Chemical reaction parameter
T Temperature
C_f Skin friction
Sh Sherwood number
u, v Velocity in x direction and y -direction respectively
x, y Cartesian coordinates along the plate and normal to it respectively
M Magnetic field parameter
V Suction/injection

GREEK LETTERS

β^* **Coefficient of expansion with concentration**
β **Coefficient of thermal expansion**
ρ **Density of fluid**
σ_0 **Stefan Boltzmann constant**
λ **Variable thermal conductivity**
σ **Electrical conductivity of the fluid**
B_0 **Magnetic field of constant strength**

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