EFFECT OF SUCTION/INJECTION ON UNSTEADY MHD NATURAL CONVECTION FLOW OF HEAT MASS TRANSFER IN POROUS CHANNEL IN THE PRESENCE OF SORET TERM

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ABSTRACT: *This research paper explores the effect of suction/injection on unsteady MHD natural convection flow of heat mass transfer in porous channel in the presence of Soret term. The governing partial differential equations are converted to non- dimensional forms and solved numerically by using unconditionally stable and convergent implicit finite difference method. A parametric study illustrating the influence of various physical parameters is performed. It is reported that the velocity profile increases as Soret term, Grashof number, Solutal Grashof number and Porous parameters values increase, while Magnetic field parameter decreases the velocity profile. The temperature profile rises by the influence in increasing values of Variable Thermal Conductivity and decreases by increasing values of Prandtl number and Radiation parameters. While concentration profile increase by the increasing values of Soret term and Chemical reaction. The dependence of the skin friction coefficient, rate of heat transfer and mass transfer on these parameter has been discussed.*

KEYWORDS: Soret term, MHD, Unsteady, Heat transfer, Mass transfer, Natural convection.

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INTRODUCTION

Soret is termed as a coupled process by which solutes are transported in a medium under the action of a thermal gradient. Soret is known as thermo-diffusion which is the ratio of temperature difference to the concentration. Srinivasacharya *et al.*(2015) studied soret and dufour effects on mixed convection along a vertical wavy surface in a porous medium with variable properties. Jha and Yusuf (2020) investigated soret and dufour effects on transient free convection heat and mass transfer flow in a vertical channel with ramped wall temperature and specie concentration: an analytical approach. Moorthy and Senthilvadivu (2012) determined soret and dufour effects on natural convection flow past a vertical surface in a porous medium with variable viscosity. Quader and Alam (2021) studied soret and dufour effects on unsteady free convection fluid flow in the presence of hall current and heat flux. Ismail et al. (2020) examined analytical and numerical study of soret and dufour effects on thermosolutal convection in a horizontal brinkman porous layer with a stress-free upper boundary. Ghulam *et al.*(2020) studied consequences of soret–dufour effects, thermal radiation, and binary Forchheimer flow of nanofluid. Idowu and Falodun (2018) investigated soret-dufour effects on MHD heat and mass transfer of Walter's-B viscoelastic fluid over a semi-infinite vertical plate: spectral relaxation analysis. Anil *et al.* (2020) studied soret and dufour effects on MHD boundary layer flow of non-Newtonian carreau fluid with mixed convective heat and mass transfer over a moving vertical plate. Shahanaz *et al.* (2020) investigated soret and dufour effects on magneto-hydrodynamics Newtonian fluid flow beyond a stretching/shrinking sheet. Bazid *et al.* (2012) studied soret and dufour numbers effect on heat and mass transfer in stagnation point flow towards a stretching surface in the presence of buoyancy force and variable thermal conductivity. Another team of researchers further by the lead of Siti et al. (2023) investigated the Soret-Dufour effects on heat and mass transfer of Newtonian over the inclined sheet and magnetic field. Nan et al. (2020) studied the physical modeling of simultaneous heat and mass transfer: species interdiffusion, Soret effect and Dufour effect. Haq *et al.* (2014) has studied Soret and Dufour effects on three dimensional MHD flow with different fluid and boundary conditions. Also, Sulochana *et al*. (2016) investigated non uniform heat source or sink effect on the flow of three dimensional Casson fluid in the presence of Soret and thermal radiations. Kameswaran *et al*. (2012) investigated the convective heat and mass transferring fluid flow over a stretching sheet when subjected to hydro magnetic, viscous dissipation, chemical reaction and Soret effects. Anwar et al. (2019) studied the effect of Soret-Dufour and radiative aspects in hydro magnetized nanofluid flow in a stratified porous medium. Also, Achogo *et al*. (2020) investigates the soret effect on MHD free convection through a porous inclined channel in the presence of thermal radiation. Sinha and Mahanta (2019) studied thermal diffusion (Soret Effect) on an unsteady MHD mixed convective heat and mass transfer flow through porous medium with chemical reaction. Kaladhar *et.al* (2016) worked on mixed convection flow of couple stress fluid in a vertical channel with radiation and Soret effects.

The main aim of this paper is to study effect of Suction/injection on unsteady MHD natural convection flow of heat and mass transfer in the porous channel in the presence of Soret term, which none of the listed literature above consider the topic mentioned which has numerous application in the field fluid dynamic like aerodynamic, space science, fiber production etc.

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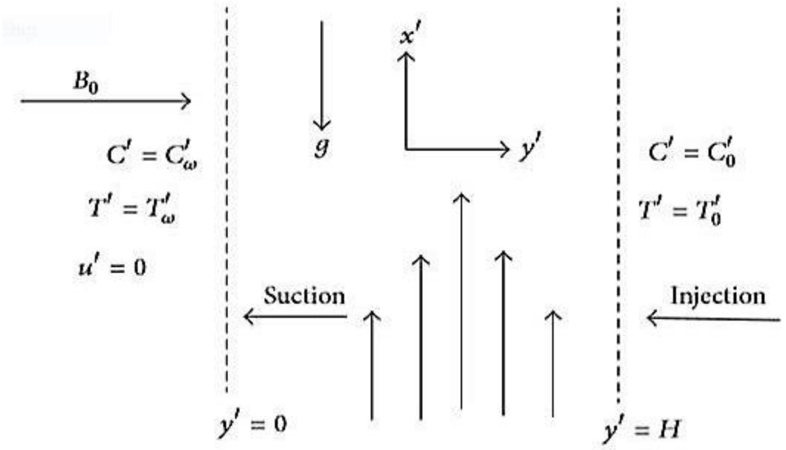
MATHEMATICAL FORMULATIONS

Consider the unsteady radiative flow of viscous incompressible fluid past a vertical channel with suction/injection and magnetic field intensity. A magnetic field B_0 of uniform strength is applied transversely to the direction of the flow. 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. The Soret term in the concentration equation has been assumed for it effect in the flow. The suction is assumed in all the three equations. The magnetic Reynolds number is assumed to be very small and hence the induced magnetic field is very small in comparison with the applied magnetic field in the absence of any input electric field. Since the plate is infinite and the fluid motion is unsteady so all the flow variables depend only on *y* and time (*t*).



Coordinate System for the Physical Model of the Problem.

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

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

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

$$\frac{\partial c'}{\partial t'} + v\frac{\partial c'}{\partial y'} = D\frac{\partial^2 c'}{\partial y^2} - R^*\left(C' - C_0'\right) + \frac{DKr}{T_m}\frac{\partial T^{'\partial}}{\partial y^{12}} \qquad (3)$$

With corresponding boundary conditions,

$$t \le 0,\ u' = 0,\ T' = 0,\ C' = 0 \qquad \forall\ y'$$
$$t \succ 0 \begin{cases} u' = 0,\ T' = T_w',\ C' = C_w' & at\ \ y' = 0 \\ u' = 0,\ T' = 0,\ C' = 0 & at\ \ y' = H \end{cases} \qquad (4)$$

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:

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Dimensionless quantities and parameters:

$$u=\frac{u'}{u_0},\ t=\frac{t'u_0}{H^2},\ y=\frac{y'}{H},\ \theta=\frac{T'-T_0'}{T_w'-T_0'}$$

$$C=\frac{C'-C_0'}{C_W'-C_0'},\ \Pr=\frac{u_0\rho C_p}{k_0},\ M=\frac{\sigma\beta_0H^2}{\rho u_0}.$$

$$Sc=\frac{u_0}{D},\ k=\frac{ku_0}{vH^2},\ K_r=\frac{R^{\bullet}H^2}{u_0}.$$

$$\lambda=\alpha\left(T'-T_0'\right),\ R=\frac{16a\sigma_0HT_0'^3}{ku_0^2}. \tag{5}$$

$$Gr=\frac{H^2g\beta\left(T_w'-T_0'\right)}{u_0^2}. \qquad Q=\frac{1}{\rho c\rho}\left(T^{'}-T_0^{'}\right)$$

$$Gc=\frac{H^2g\beta^{\bullet}\left(C_w'-C_0'\right)}{u_0^2}.\ \ V=\frac{v}{u_0},\ \ Sr=\frac{DKr}{T_m}\frac{\partial T'^{\partial}}{\partial y^{12}},$$

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:

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

Using equation (5), equation (1) to (4) becomes

$$\frac{\partial u}{\partial t}+V\frac{\partial u}{\partial y}=v\frac{\partial^2u}{\partial y^2}-Mu-\frac{1}{k^*}u+Gr\theta+GcC \tag{7}$$

$$\frac{\partial\theta}{\partial t}+V\frac{\partial\theta}{\partial y}=\frac{\lambda}{\Pr}\left(\frac{\partial\theta}{\partial y}\right)^2+\frac{1}{\Pr}(1+\lambda\theta)\frac{\partial^2\theta}{\partial y^2}-R\theta \tag{8}$$

$$\frac{\partial C}{\partial t}+V\frac{\partial C}{\partial y}=\frac{1}{Sc}\frac{\partial^2C}{\partial y^2}-KrC+\frac{Sr}{Sc}\frac{\partial^2\theta}{\partial y^2} \tag{9}$$

With corresponding boundary conditions,

$$\begin{aligned}&t\le 0,\ u'=0,\ T'=0,\ C'=0 \qquad \forall\ y'\\ &t\succ 0\begin{cases}u'=0,\ T'=T_w',\ C'=C_w' & at\ \ y'=0\\ u'=0,\ T'=0,\ C'=0 & at\ \ y'=H\end{cases}\end{aligned} \tag{10}$$

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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:

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

(11)

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

(12)

$$\left(\frac{C_i^{j+1}-C_i^j}{\Delta t}\right)+V\frac{\left(C_i^{j+1}-C_i^{j+1}\right)}{\Delta y}=\frac{1}{Sc}\frac{\left(C_{i+1}^{j+1}-2C_i^{j+1}+C_{i-1}^{j+1}\right)}{(\Delta y)^2}+\frac{Sr}{(\Delta y)^2}\left(\theta_{i+1}^{j+1}-2\theta_i^{j+1}+\theta_{i-1}^{j+1}\right)-KrC_i^j$$

(13)

The initial and boundary conditions may be expressed as:

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

Where H correspond to 1.

The Solutions of equations (11), (12) and (13) are as follows:

$$-r_1u_{i-1}^{j+1}+r_3u_i^{j+1}-r_1u_{i+1}^{j+1}=r_4u_i^j-r_2u_{i+1}^j+r_5\theta_i^j+r_6C_i^j \tag{15}$$

$$-\Pr_1\theta_{i+1}^{j+1}+\left(1+2\Pr_1\right)\theta_i^{j+1}-\Pr_1\theta_{i-1}^{j+1}=\left(1-r_2-r_4\right)\theta_i^j-r_2\theta_{i+1}^j+r_3\left(\theta_{i+1}^j-\theta_i^j\right)^2 \tag{16}$$

$$-r_1C_{i-1}^{j+1}-r_{13}\theta_{i-1}^{j+1}+r_{14}C_i^{j+1}+2r_{13}\theta_i^{j+1}-r_1C_{i+1}^{j+1}-r_{13}\theta_{i+1}^{j+1}=-r_{12}C_{i+1}^j+r_{15}C_i^j \tag{17}$$

With corresponding boundary conditions,

$$\begin{array}{l} t\le 0,\ u'=0,\ T'=0,\ C'=0 \qquad \forall\ y' \\ t\succ 0\left\{\begin{array}{ll} u'=0,\ T'=T'_w,\ C'=C'_w & at\ \ y'=0 \\ u'=0,\ T'=0,\ C'=0 & at\ \ y'=H \end{array}\right\} \end{array} \tag{18}$$

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.

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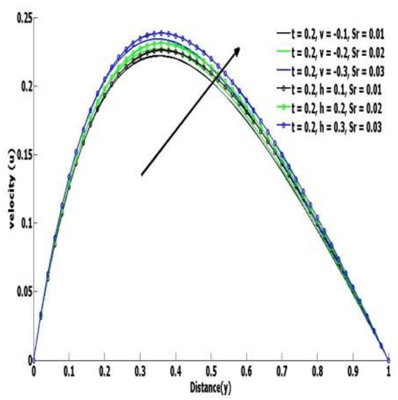
RESULTS AND DISCUSSION

This section, constitute the analysis of the fluid flow, numerical computations is carried out for various values of the major parameters such as, Soret term, 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:

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



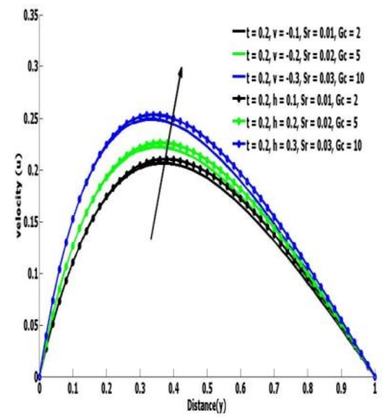
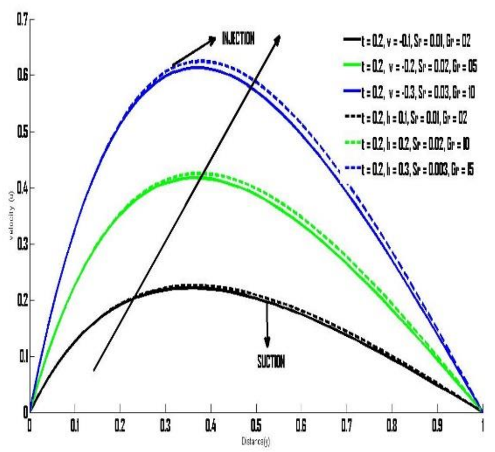


Fig_1 Velocity profile with different values of Soret term (*Sr*). Fig_2 Velocity profile with different values of Solutal Grashof number (*Gc*).



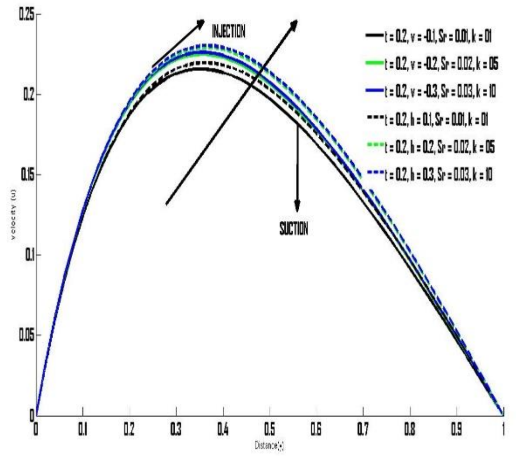


Fig_3 Velocity profile with different values of Thermal Grashof number (*Gc*). Fig_4 Velocity profile with different values of Porous parameter (*k*).

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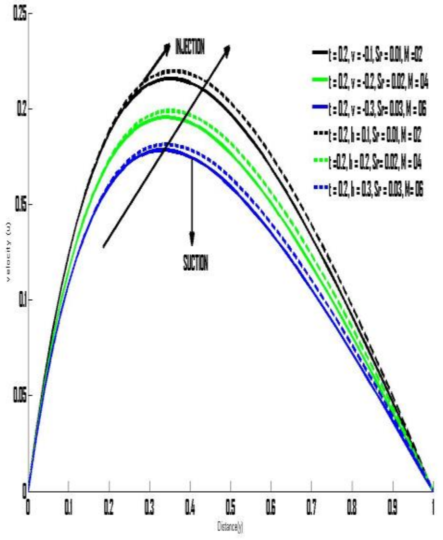


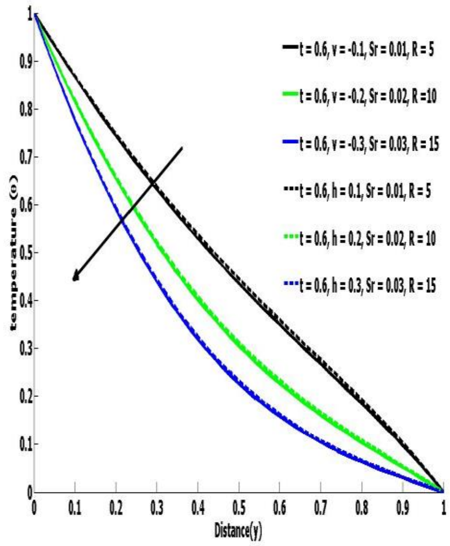
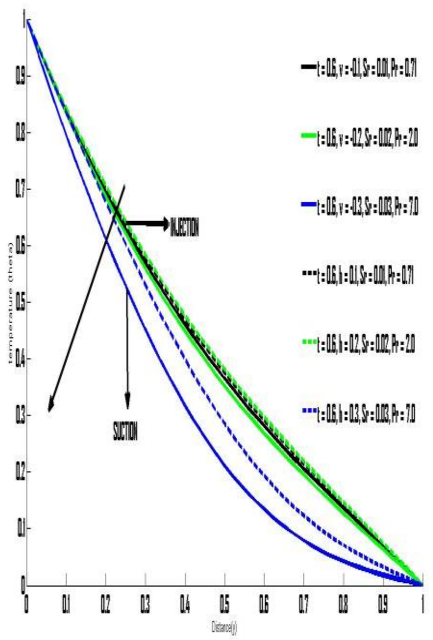


Fig_5 Velocity profile with different values of Magnetic Field parameter (*M*). Fig_6 Temperature profile with different values of Radiation (*R*).



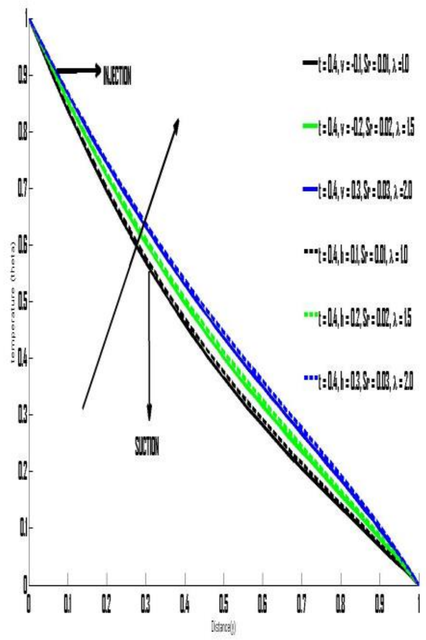


Fig_7 Temperature profile with different values of Prandtl number (Pr) parameter. Fig_8 Temperature profile with different values of Variable thermal conductivity (λ).

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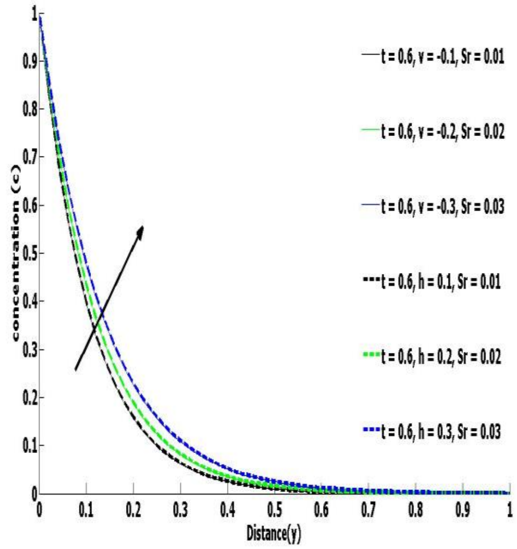


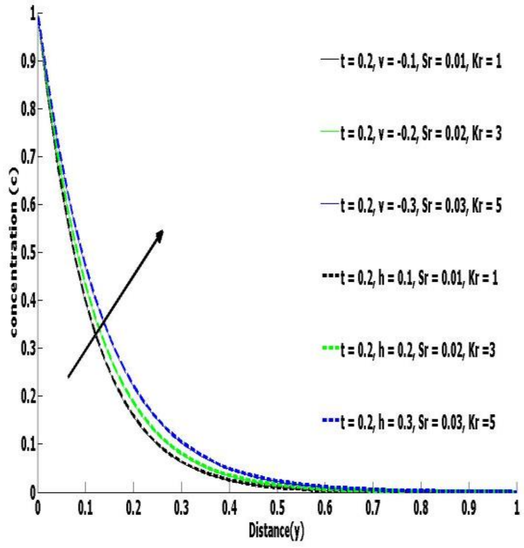
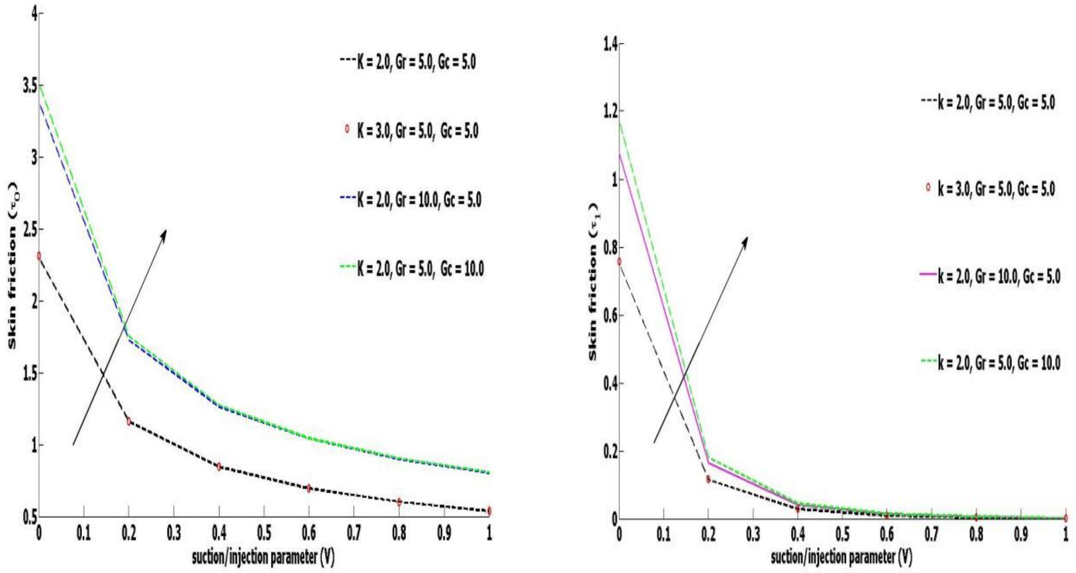


Fig_9 Concentration profile with different values of Soret number (*Sr*). Fig_10 Concentration profile with different values of Chemical reaction (*Kr*).



Figs. 11(a) & (b): 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.

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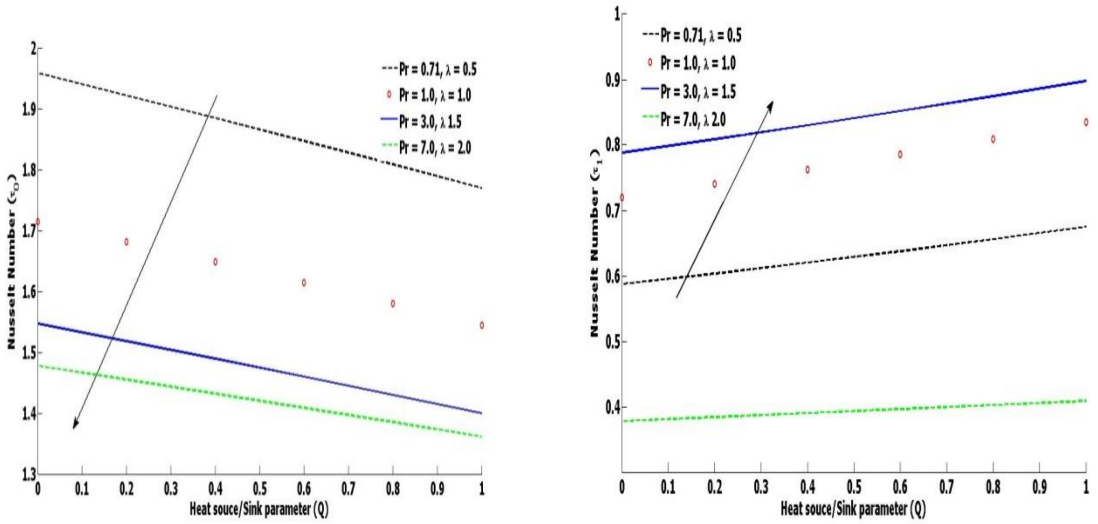
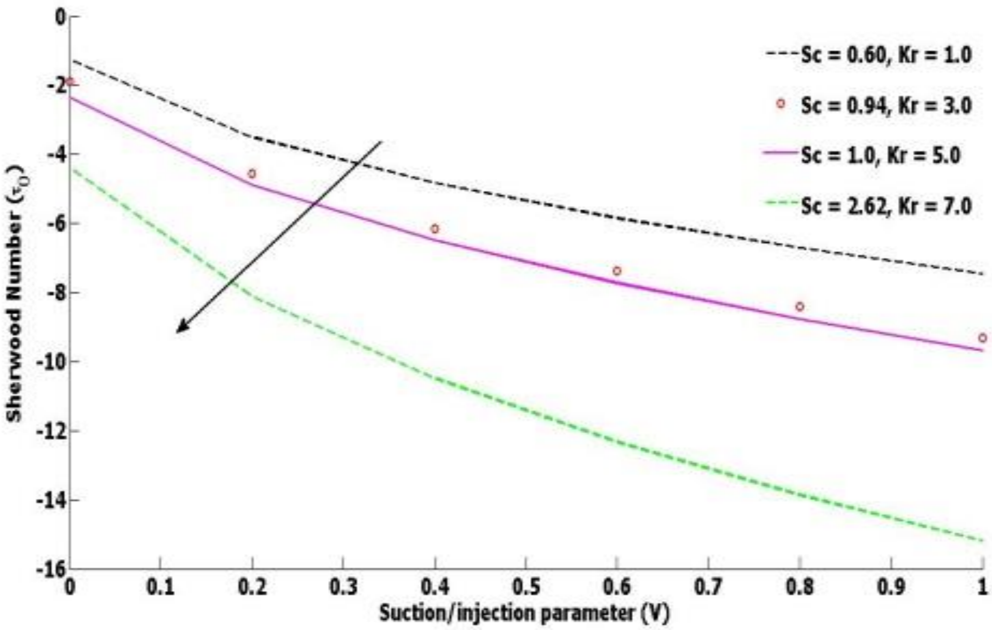


Figs. 12(a) & (b): Effect of Suction/injection (V) on nusselt number with Pr = 0.71, Lmd = 0.5, V = 0, 0.2, 0.4, 0.6, 0.8 &1.



Figs. 13 (a): 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.

Figure (1) and (2) presented the response of the fluid velocity to variations in the soret number *Sr* and solutal grashof number *Gc* in the presence of suction and injection. Figure (1) shows the effect of Soret number on the velocity with constant suction and injection. In this figure, it is noted that Soret number increases the fluid velocity in the presence of suction and injection. Figure (2) reveal that increasing of solutal Grashof number increases velocity profile in the presence of soret number both in terms of suction and injection. This is due to

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the cooling of the plate. Figure (3) and (4) illustrate the behavior of thermal Grashof number *Gr* and *k* on the velocity profiles in case of cooling the plate. It is noticed that *Gr* and *k* enhance the velocity profiles of the fluid both in the case of suction and injection. The effect of magnetic field parameter *M* in case of cooling the plate on the velocity profile is depicted in figure (5). It is found that the velocity increases with increasing in case of injection and decreases in case of suction. Figure (6) describe the behavior of temperature profile for different values of Radiation parameter *R*. The effect of Radiation parameter *R* on temperature profile is graphically demonstrated in figure (6). It is marked from this figure that as Radiation increases considerable reduction is seen in temperature profile both in terms of suction and injection. The effect of Prandtl number *Pr* on the temperature profile is depicted in figure (7). It is found that the temperature decreases by the increasing of prandtl number in case of suction and increases by the increasing of prandtl number in the case of injection. Figure (8) reveals the transient temperature profile against y (distance from the plate) for different values of thermal conductivity λ parameter. It is shown that as λ increases for both suction and injection then total increases in temperature profile is considered. This result to thermal boundary thickness thereby increasing the temperature profile. The effects of Soret number *Sr* and Chemical reaction *Kr* on concentration profiles are presented graphically in figure (9) and (10) respectively. It is observed that concentration of the fluid increases with increasing values of *Sr* and *Kr* in case of suction and injection. It is also, noticed that concentration boundary layer becomes thin as Soret number as well as chemical reaction increases. Figs. 11 (a) and (b) 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. 12(a) and (b) 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. Figure. 13(a) demonstrates the graph of Sherwood number and noticed that Sherwood number deceases by the increasing of Schmidt number (Sc) and Chemical reaction (Kr) parameters.

CONCLUSION

The following conclusions are made from the present investigation:

1. Velocity profiles increases with increasing values of Soret term, Porous (k), Magnetic field (M), Thermal Grashof number (Gr) and Solutal Grashof number (Gc).

2. Temperature profiles decreases with increasing of Radiation and Prandtl number, while increasing with increase of Variable thermal conductivity.

3. Concentration Profiles increases with increasing values of Soret term and Chemical reaction (Kr) parameters.

4. The skin friction coefficient increases with increasing values of Porous (k), Thermal Grashof number (Gr), Solutal grashof number (Gc) and Suction/injection parameters.

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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.

6. The rate of concentration transfer decreases with increasing values of Schmidt number (Sc), Chemical reaction (Kr) and Suction/injection (V) parameters.

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APPENDIX

$$r_3 = 1 + 2r_1\ ;\ \ r_4 = 1 + r_2 - P\Delta t\ ;\ r_5 = \Delta t Gr\theta_i^j \ \text{ and }\ r_6 = \Delta t GcC_i^j$$

$$q = \left(\frac{1 + \lambda\theta_i^j}{\Pr}\right)\ ;\ r_1 = \frac{\Delta t}{(\Delta y)^2}\ ;\ \ r_2 = \frac{V\Delta t}{\Delta y}\ ;\ r_7 = \frac{\lambda\Delta t}{\Pr(\Delta y)^2}\ ;\ r_8 = \frac{R\Delta t}{\Pr}\theta_i^j$$

$$r_9 = -qr_1\ ;\ r_{10} = 1 + 2qr_1\ ;\ r_{11} = (1 - r_2 - r_4)\ ;$$

$$r_1 = \frac{\Delta t}{(\Delta y)^2}\ ;\ r_{12} = \frac{VSc\Delta t}{\Delta y}\ ;\ r_{13} = \frac{\Delta t Sr}{Sc(\Delta y)^2}\ .$$

$$r_{14} = Sc + 2r_1\ \ ;\ \ r_{15} = Sc + r_{12} - \Delta t ScKr$$

NOMENCLATURE

C	Concentration
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
Sr	Soret term

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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