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Research Article

Soret and Heat Source Effects on MHD Convection Flow Past an infinite Vertical Plate Embedded in Porous Medium in presence of Viscous, Joules Dissipation and Chemical Reaction

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ABSTRACT:
Aim of this paper is to investigate the effects of Soret and heat source on steady MHD mixed convective heat and mass transfer flow over an infinite vertical plate embedded in porous medium with viscous, Joules dissipation and chemical reaction. The governing partial differential equations are transformed to the ordinary differential equations using similarity variables and then solved numerically using MATLAB in built solver. The effects of physical parameters on velocity, temperature and concentration as well as skin friction coefficient, Nusselt number and Sherwood number are computed and presented in graphical and tabular forms. Comparisons with previously published work are performed and the results are found to be in excellent agreement.

Keywords: Chemical reaction, Heat source, MHD, Soret number, Joules dissipation.

1.INTRODUCTION:

The study of mixed convection has been the object of extensive research, importance of this study is increasing nowadays, mixed convection flow through porous medium has received considerable attention with numerous industrial applications in hydrodynamics, chromatography, geothermal energy recovery, oil extraction thermal energy storage, crystal magnetic damping control, chemical catalytic reactors, geophysics, energy related engineering problems including polymer sheets and metal sheets, and also the analysis of heat and mass transfer with chemical reaction assumes great practical importance to engineers and scientists because of its universal occurrence in many branches of science and engineering particularly, the study of chemical reaction, heat and mass transfer with radiation is of considerable importance in chemical and Hydrometallurgical industries. A comprehensive review of thestudies of convective heat transfer mechanism through porous media has been made by Nield and Bejan [1]. Chaudhary and Sharma [2] considered combined heat and mass transfer by laminar mixed convection flow from a vertical surface with induced magnetic field. Hydromagnetic unsteady mixed convection and mass transfer flow past a vertical porous plate immersed in a porous medium was investigated by Sharma and Chaudhary [3]. El-Amin [4] considered the MHD free convection and mass transfer flow in a micro polar fluid over a stationary vertical plate with constant suction.

Many researchers have studied on MHD free convective heat and mass transfer flow in a porous medium; some of them are Raptis and Kafoussias [5], Sattar [6]. The MHD boundary layer flow of nanofluid and heat transfer over a nonlinear stretching sheet with chemical reaction and suction/blowingwas studied by Dharmendar Reddy et. al. [7]. Ahmed [8] investigated the effect of transverse periodic permeability oscillating with time on the heat transfer flow of a viscous incompressible fluid through a highly porous medium bounded by an infinite vertical porous plate, by means of series solution method, he studied the effect of transverse periodic permeability oscillating with time on the free convective heat transfer flow of a viscous incompressible fluid through a highly porous medium bounded by an infinite vertical porous plate subjected to a periodic suction velocity.

Coupled heat and mass transfer problems with chemical reaction gain importance in many processes such as drying,distribution of temperature and moisture over agricultural fields and groves of a water body, energy transfer in wet cooling tower and flow in a desert cooler, heat and mass transfer occur simultaneously and received a considerable amount of attention in recent years.Many practical diffusive operations involve the molecular diffusion of a species in the presence of chemicalreaction with in or at the boundary.Therefore, the study of heat and mass transfer with chemical reaction is of great practical importance to engineering and scientists. Yanala Dharmendar Reddy et. al. [9] presentedMHD boundary layer flow of nanofluid and heat transfer over a porous exponentially stretching sheet in presence of thermal radiation and chemical reaction with suction. Seddeek and Almushigeh[10] investigated the effects of radiation and variable viscosity on MHD free convection over a stretching sheet under the influence of variable chemical reaction.Alharbi et. al. [11] founded the Heat and mass transfer in MHD visco-elastic fluid flow through a porous medium over a stretching sheet with chemical reaction. In many chemical processes, a chemical reaction occurs between a foreign mass and a fluid in which a plate is moving. These processes take place in numerous industrial applications, e.g., polymer production, manufacturing of ceramics or glassware, and food processing Cussler [12]. Chamkha [13] presented an analytical solution for heat and mass transfer by laminar flow of aNewtonian, viscous, electrically conducting fluid and heat generation/absorption.

The mass transfer caused by temperature gradient is called the Soret effect, Soret and Dufour effects are important phenomena in areas such as hydrology, petrology and geo-sciences. The Soret effect for instance has been utilized for isotopeseperation and in a mixture between gases with very light molecular weight (He,H2) and of medium molecular weight (N2,air). Many researchers studied Soret and Dufour on heat and mass transfer. Chamkha and El Kabeir [15] presentedatheoreticalstudyofSoretand Dufoureffectsonunsteadycoupledheatandmasstransfer bymixedconvectionflowoveraverticalconerotatinginan ambientfluidinthepresenceofamagneticfieldandchemical reaction,the influence of Soret effect and the flow of electrically conducting fluid past a vertical plate in the presence of various physical parameters has been studied by some researchers. Shankar Goud and Dharmendar Reddy Yanala[16] have studied the radiation and magnetic field effects of free convective flow over a linearly moving permeable vertical surface in the presence of suction. Jha BKand Singh AK[17] investigated the Soret effect on free convection and mass transfer flow in the Stokes problem for an infinite vertical plate. Due to the importance of Soret (thermal-diffusion) and Dufour (diffusion thermo) effects for the fluids with very light molecular weight as well as medium molecular weight, many investigators have studied and reported results for these flows of whom the names are Shankar Goud[18], Dursunkaya and Worek [19], Anghel et al., [20],Mahender et.al[25], Postelnicu [21] are worth mentioning. Alam and Rahman [22] studied the Dufour and Soret effects on steady MHD free convective heat and mass transfer flow past a semi infinite vertical porous plate embedded in a porous medium.

The viscous as well as Joules dissipation along with heat generation was taken into account in the energy equation. Duwairi[23]analyzedviscousand joule-heating effects on forced convection flow from radiate isothermalsurfaces.The effect ofviscousdissipationisusu-allycharacterizedbytheEckertnumberandhasplayedavery importantroleingeophysicalflowandinnuclearengineering thatwasstudiedbyAlimetal.[24]. The effect of combined Joules and viscous dissipation on mixed convection MHD flow in a vertical channel was noticed by Abo-Eldahab and El-Aziz [26].

The aim of this paper is to discuss the effects of Soret and chemical reaction on steady MHD convective heat and mass transfer flow past a vertical porous plate placed in porous medium in the presence of heat source, viscous and Joules dissipation the governing equations are transformed by using similarity transformations and the resultant dimension less equations are solved numerically using MATLAB inbuilt solver,the effects of different physical parameters on velocity, temperature and concentration profiles as well as the skin friction coefficient, Nusselt and Sherwood numbers are presented graphically and represented in tabular form.

2.MATHEMATICAL FORMULATION

We consider the mixed convection flow of an incompressible and electrically conducting viscous fluid such that x^*- axis is taken along the plate in upward direction and y^*-axis is normaltoit(seeFig.1).Atransverseconstantmagneticfieldisapplied,i.e. in the direction of y^*-axis. Since the motion is two dimensional and length of the plate is large therefore all the physical variables are independent of x^*. A homogenous first order chemical reaction between fluid and the species concentration is considered, in which the rate of chemical reaction is directly proportional to the species concentration.

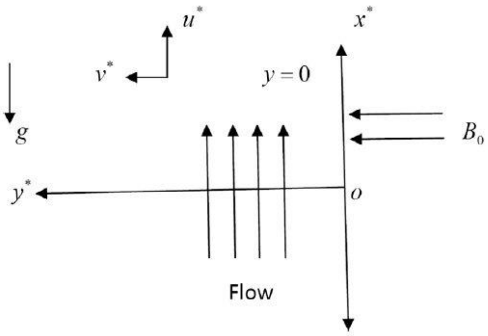

Fig.1: Sketch of thephysicalmodel.

The governing equations of continuity, momentum, energy and mass for a flow of an electrically conducting fluid are given by thefollowing:

$$\frac{\partial v^*}{\partial y^*} = 0 \Rightarrow v^* = -v_0 (v_0 > 0) \qquad (1)$$

$$v^* \frac{du^*}{dy^*} = v \frac{d^2 u^*}{dy^{*2}} + g\beta(T^* - T_\infty) + g\beta^*(C^* - C_\infty) - \frac{\sigma B_0^2}{\rho} u^* - u^* \frac{v}{k^*} \qquad (2)$$

$$v^* \frac{dT^*}{dy^*} = \frac{k}{\rho C_p} \frac{d^2 T^*}{dy^{*2}} + \frac{v}{C_p} \left(\frac{du^*}{dy^*}\right)^2 + \frac{\sigma B_0^2}{\rho C_p} u^{*2} + \frac{Q_0}{\rho C_p} (T^* - T_\infty) \qquad (3)$$

$$v^* \frac{dC^*}{dy^*} = D \frac{d^2 C^*}{dy^{*2}} + D_1 \frac{d^2 T^*}{dy^{*2}} - k_1 (C^* - C_\infty) \qquad (4)$$

where u^* and v^* are the components of velocity in x^* and y^*directions, respectively, taken along and perpendicular to the plate, g is the acceleration due to gravity, β is the coefficient of thermal expansion, β^* is the coefficient of mass expansion, T^* is the temperature of the fluid, T_∞ is the temperature far away from the plate, T_w is the temperature near the plate. $C^*$is the concentration of the fluid, C_w is the concentration near the plate, C_∞ is the concentration far away from the plate, υ is the kinematic viscosity of the fluid, σ is the magnetic permeability of the fluid, k^* is the permeability of porous medium, ρ is the fluid density, B_0 is the magnetic field coefficient, C_p is the specific heat of the fluid at constant pressure, v_0 is the constant suction velocity, D is the chemical molecular diffusivity, D_1 is the coefficient of thermal diffusivity and k_1 is the chemical reaction rate constant.

The boundary conditions for the velocity, temperature and concentration fields are

$$\begin{aligned} y^* &= 0: u^* = 0; T^* = T_w; C^* = C_w \\ y^* &\to \infty: u^* \to 0; T^* \to T_\infty; C^* \to C_\infty \end{aligned} \qquad (5)$$

Introducing following non-dimensional quantities

$$y=\frac{y^{*}v_{0}}{v},u=\frac{u^{*}}{v_{0}},\Pr=\frac{v\rho C_{p}}{k},\theta=\frac{T^{*}-T_{\infty}}{T_{w}-T_{\infty}}$$
$$\phi=\frac{C^{*}-C_{\infty}}{C_{w}-C_{\infty}},Gr=\frac{\mathrm{vg}\ \beta(T_{w}-T_{\infty})}{v_{0}^{3}}$$
$$Gm=\frac{\mathrm{vg}\ \beta^{*}(C_{w}-C_{\infty})}{v_{0}^{3}},Ec=\frac{v_{0}^{2}}{C_{p}(T_{w}-T_{\infty})} \qquad (6)$$
$$M^{2}=\frac{\sigma B_{0}^{2}v}{\rho v_{0}^{2}},k^{*}=\frac{v}{Kv_{0}^{2}},v=\frac{\mu}{\rho}$$
$$Sc=\frac{v}{D},So=\frac{D_{1}(T_{w}-T_{\infty})}{v(C_{w}-C_{\infty})},Kr=\frac{vk_{1}}{v_{0}^{2}},Q=\frac{Q_{0}v}{\rho c_{p}v_{0}^{2}}$$

where Gr is the Grashof number, Gm is the mass Grashofnumber,PristhePrandtlnumber,ScistheSchmidtnumber,$So$is the Soret number, Ec is the Eckert number, M is the magnetic parameter, K is the permeability of porous medium and Kr is the chemical parameters.

In set of Eqs. (2)–(4), we obtain the governing equations in the dimensionless form as

$$u''+u'-(M^{2}+K)u=-Gr\theta-Gm\phi \qquad (7)$$

$$\theta''+\Pr\theta+\Pr Ec(u')^{2}+\Pr EcM^{2}u^{2}+\Pr Q\theta=0 \qquad (8)$$

$$\phi''+Sc\phi'-ScKr\phi+SoSc\theta''=0 \qquad (9)$$

The corresponding boundary conditions in dimensionless form are reduced to

$$\left.\begin{array}{l} y=0: u=0;\theta=1;\phi=1 \\ y\to\infty: u\to 0;\theta\to 0;\phi\to 0\end{array}\right\} \qquad (10)$$

3.NUMERICAL SOLUTION

The nonlinear ordinary differential equations (7-8) along with boundary conditions (10) are incorporated with the help of MATLAB tool bvp5c. To get this, the set of ordinary differential equations are first transformed to first order ordinary differential equations by using the successive substitutions

$$u=f_{1},u'=f_{2},\theta=f_{3},\theta'=f_{4},\phi=f_{5},\phi'=f_{6}$$
$$f_{1}'=-f_{2}+(\mathrm{M}^{2}+\mathrm{K})f_{1}+\mathrm{Gr}\,\theta+\mathrm{Gm}\,\phi$$
$$f_{4}'=-\left(\Pr\theta+\mathrm{PrEc}(f_{2})^{2}+\mathrm{PrEcM}^{2}\left(f_{1}\right)^{2}+\mathrm{PrQ}\theta\right)$$
$$f_{6}'=-\left(\mathrm{Sc}f_{6}-\mathrm{ScKr}f_{5}+\mathrm{SoSc}f_{4}'\right)$$

The boundary conditions can change into following form

$$f_{1}(0)=0,\ f_{3}(0)=1,\ f_{5}(0)=1, \qquad : \quad \eta\to 0;$$
$$f_{1}(\eta_{\infty})=0,\ f_{3}(\eta_{\infty})=0,\ f_{5}(\eta_{\infty})=0: \quad \eta\to\infty$$

The asymptotic boundary condition (7-10) at the margin was stable to 10^{-6}. In this approach, the choice of $\eta_{\infty}=5$, in agreement with standard practice in the boundary layer analysis.

4.RESULTS AND DISCUSSION

From numerical computations dimensionless velocity, temperature and concentration profiles as well as the Skin friction coefficient, Nusselt number and Sherwood number are found for different values of the various physical parameters occurring in the problem are magnetic fieldparameter M,permeabilityofporousmedium$K$,thermalGrashofnumberGr,massGrashofnu mber Gm ,Prandtl number Pr ,Eckertnumber Ec ,heatgenerationparameter Q, Schmidt numberSc,chemical reaction, $Kr$and Soretnumber So. In the present study, the following default parametervalues are adopted for computations:$Gr = 3.0, Gm = 1.0, K = 1.0, M = 1.0, Pr = 0.71, Ec = 0.001,\ Q = 0.1, Sc = 0.6, Kr = 0.1, So = 0.5$.

The effect of Grashof number Gron the velocity field is presented in Fig.2. The Grashof number Gr signifies the relative effect of the thermal buoyancy force to the viscous hydrodynamic force in the boundary layer. As Grashof number Grincreases the velocity oh the fluid increases. From Fig.3 it is observed that the dimensionless velocity increases with increase of mass Grashof number Gm. The effect of permeability parameter Kon the velocity field is shown in Fig.4.As the permeability parameter K increases the velocity of the fluid increases. Figs. 5&6 shows the velocity and temperature profiles for different values of Prandtl number Pr.The numerical results show that the effect of increasing values of Pr results in a decreasing velocity and temperature. The reason is that the smaller values of $Pr$are equivalent to increasing the thermal conductivities and therefore heat is able to diffuse away from the heated surface more rapidly than for higher values of Pr. Hence in the case of smaller Prandtl number as the boundary layer is thicker and rate of heat transfer is reduced. Fig. 7&8 illustrate the velocity and temperature profiles for different values of Ec. It is seen that the effect of increasing values of Ecresults in increase in both velocity and temperature profiles. The effect of heat generation parameter Qon the temperature and velocity are shown in Fig. 9 & 10 respectively. It is noticed that an increase in Qresults in an increase in temperature and velocity. The influence of Schmidt number Sc on the velocity and concentration profiles is plotted in Fig. 11 & 12 respectively. As Scincrease the concentration decreases. The Soret effect *So* on velocity and concentration profiles are shown in Figs. 13 &14 respectively. It is seen that the effect of increasing values of*So* results in decreasing both velocity and concentration. From Fig. 15 & 17 shows the velocity and concentration profiles for different values of chemical reaction parameter Kr. The numerical results show that the effect of increasing values of Kr results in decreasing velocity and concentration. From Fig. 16 it is observed that the velocity decreases with increase of Magnetic field parameter M.

The effects of various governing parameters on the Skin friction $\boldsymbol{Cf}$, Nusselt number $\boldsymbol{Nu}$, and

the Sherwood number $\boldsymbol{Sh}$ are shown in Tables1,2 and 3.

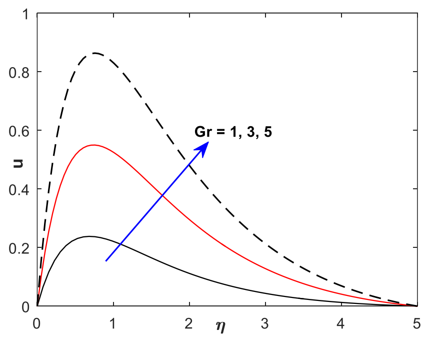

Fig. 2: Velocity profiles for different values of Gr.

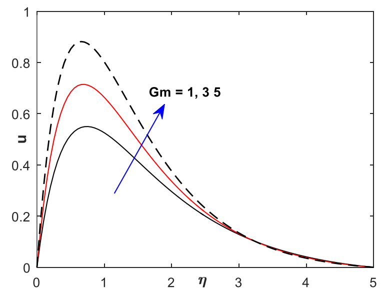

Fig. 3: Velocity profiles for different values of Gm.

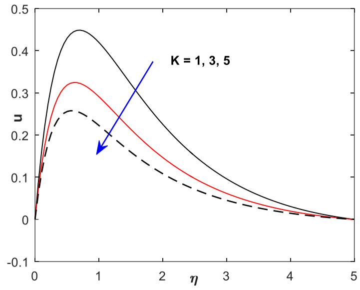

Fig. 4: Velocity profiles for different values of K.

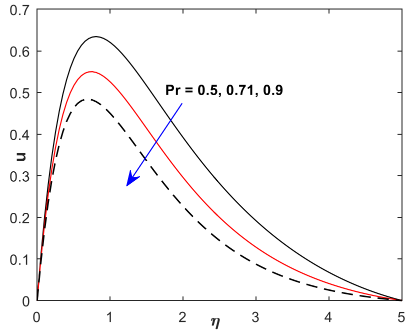

Fig. 5: Velocity profiles for different values of Pr.

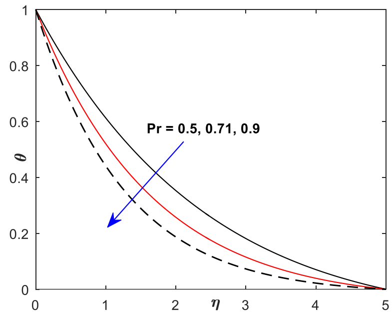

Fig. 6: Temperature profiles for different values of Pr.

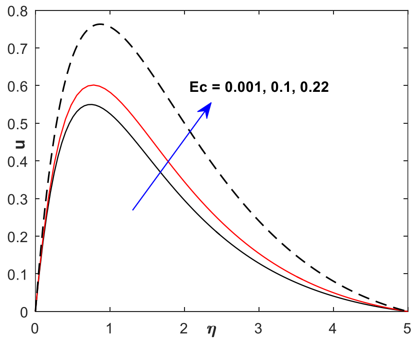

Fig. 7: Velocity profiles for different values of Ec.

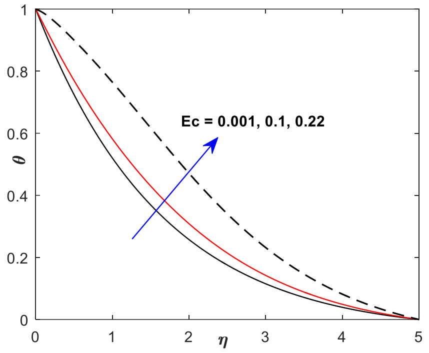

Fig. 8: Temperature profiles for different values of Ec.

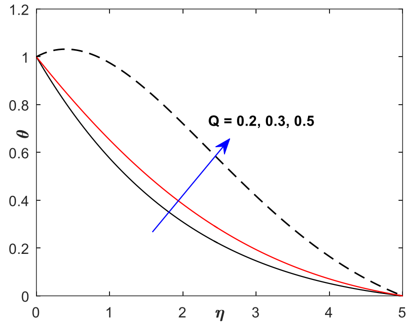

Fig. 9: Temperature profiles for different values of Q

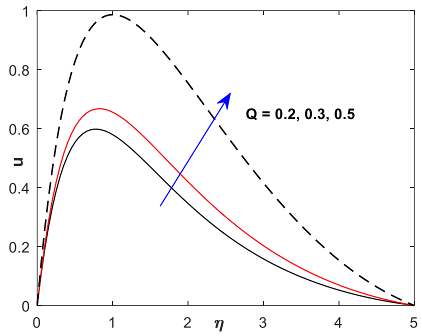

Fig. 10: Velocity profiles for different values of Q

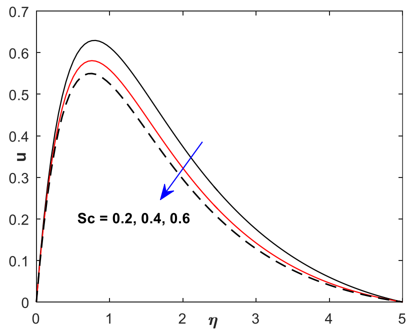

Fig. 11: Velocity profiles for different values of Sc

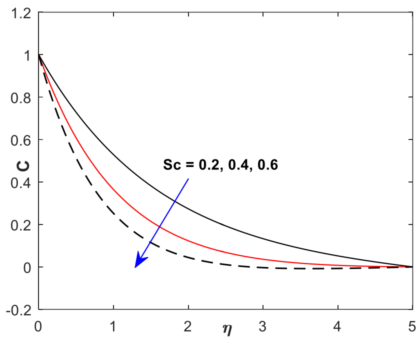

Fig. 12: Concentration profiles for different values of Sc

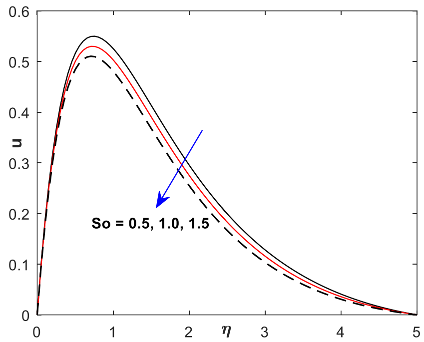

Fig. 13: Velocity profiles for different values of So

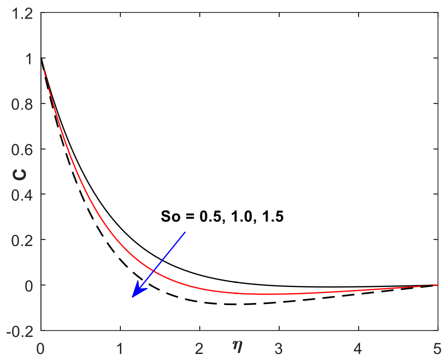

Fig. 14: Concentration profiles for different values of So

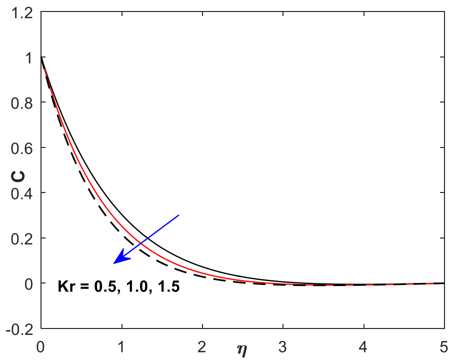

Fig. 15: Concentration profiles for different values of Kr

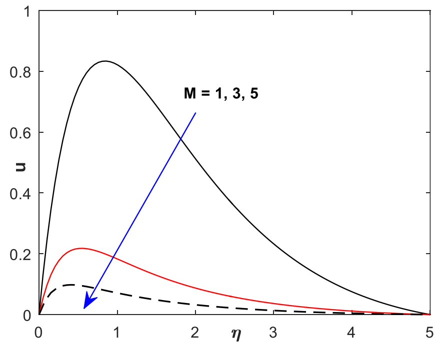

Fig. 16: Velocity profiles for different values of M

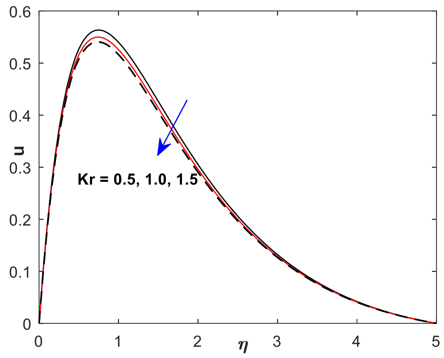

Fig. 17: Velocity profiles for different values of Kr

From Table. 1 it is noticed that as $\boldsymbol{Gr}, \boldsymbol{Gm}$ increases the Skin friction coefficient $\boldsymbol{Cf}$ increases.Where as the increase of Magnetic field parameter M and permeability of porous medium $\boldsymbol{K}$ the Skin friction coefficient $\boldsymbol{Cf}$ decreases.From Table. 2 it is clear that the increase of prandtl number $\boldsymbol{Pr}$,the Nusselt number *Nu* increases. Where as the increase of $\boldsymbol{Q}$ and $\boldsymbol{Ec}$,the Nusselt number $\boldsymbol{Nu}$ decreases. From Table. 3 it is observed that the increase of $\boldsymbol{Sc}$ and $\boldsymbol{Kr}$, the Sherwood number $\boldsymbol{Sh}$ increases. Where as the increase of $\boldsymbol{So}$,the Sherwood number $\boldsymbol{Sh}$ decreases.

In order to assess the accuracy of the numerical results,we have compared our results with the existing results of S.M.Ibrahim et al.[27].Comparision with existing results shows good agreement as presented inTable. 4.

Table 1: Effect of various physical parameter on skin friction for $Pr = 0.71, Ec = 0.001, Q = 0.1, Sc = 0.6, Kr = 0.1, So = 0.5$ values.

Gr	Gm	M	K	Cf	Nu	Sh
3	1	1	1	2.165212	-0.63784	-0.952165
5	1	1	1	3.295937	-0.635867	-0.952076
7	1	1	1	4.429999	-0.633033	-0.951948
3	3	1	1	3.111167	-0.63656	-0.952117
3	5	1	1	4.05724	-0.634864	-0.952056
3	1	3	1	1.218321	-0.638715	-0.952203
3	1	5	1	0.760896	-0.639028	-0.952217
3	1	1	1.5	1.793006	-0.638477	-0.952196
3	1	1	2	1.701186	-0.638598	-0.952201

Table 2 : Effects of various physical parameter on Nusselt number $Gr = 3.0, Gm = 1.0, K = 1.0, Sc = 0.6, Kr = 0.1, So = 0.5$ values

Pr	Ec	Q	Cf	Nu	Sh
0.71	0.001	0.1	2.1652	-0.63784	-0.952165
1	0.001	0.1	1.9586	-0.902338	-0.966260
1.5	0.001	0.1	1.6837	-1.393098	-0.979946
0.71	0.002	0.1	2.1662	-0.636409	-0.952103
0.71	0.003	0.1	2.1672	-0.634974	-0.952041
0.71	0.001	0.05	2.1255	-0.685829	-0.954952
0.71	0.001	0.07	2.1408	-0.667159	-0.953886

Table 3: Effects of various physical parameter on Sherwood number $Gr = 3.0, Gm = 1.0, M = 1.0, K = 1.0, Pr = 0.71, E = 0.001, Q = 0.1$ values.

Sc	Kr	So	CF	Nu	Sh
0.6	0.1	0.5	2.8426	-0.637118	-0.952138
1	0.1	0.5	2.6398	-0.637555	-1.521384
1.5	0.1	0.5	2.4787	-0.637827	-2.243378
0.6	0.3	0.5	2.8086	-0.637196	-1.045623
0.6	0.5	0.5	2.7822	-0.637253	-1.126897
0.6	0.1	1.0	2.7158	-0.637421	-1.200560
0.6	0.1	1.5	2.589	-0.637695	-1.146920

Table 4: Computations showing comparison with Ibrahim et al. [27] results for $Gr = 5.0, Gm = 2.0, Pr = 1.0, Ec = 0.001, Q = 0.0, K = 0.0$

M	So	Kr	Sc	Skin friction Cf		Nusselt number Nu		Sherwood number Sh	
				Ibrahim et al. [27]	Present Study	Ibrahim et al. [27]	Present Study	Ibrahim et al. [27]	Present Study
2	2	0.1	0.22	3.3005	3.3017	-0.9276	-0.9283	-0.1810	-0.1823
5	2	0.1	0.22	1.3308	1.3287	-1.1724	-1.1730	-0.0873	-0.0865
2	4	0.1	0.22	2.9593	2.9537	-1.0791	-1.0789	-0.2113	-0.2179
2	2	0.3	0.22	3.0311	3.0267	-1.3159	-1.3147	-0.0935	-0.0968
2	2	0.1	0.3	2.9372	2.9353	-1.2167	-1.2163	-0.0486	-0.0479

5. CONCLUSIONS

In this paper we have studied the effects of Soret, heat source, chemical reaction on steady MHD mixed convective flow and heat- mass transfer past an infinite vertical plate with viscous Joules dissipation. The expressions for temperature and concentration distributions which are the equations governing the flow are numerically solved by bvp5c MATLAB in built solver.

The effects of various governing parameters on the Skin friction, Nusselt number and Sherwood number are shown in tables. The conclusions of the study are as follows.

- The velocity increases with the increase of Gr, Gm
- The velocity decreases with increase of magnetic field parameter $M$and$K$.
- The temperature decreases with increase of Pr
- Velocity are temperature increases with increase of heat source parameter Q
- Velocity and concentration decreases with increase of $So$and Kr
- Velocity and concentration decreases with increase of Sc
- Skin friction Cfincreases with increase of Gr andGm

- Skin friction Cfdecreases with increase of $M$and K
- Nusselt number Nu increases with increase of Pr
- Nusselt number Nu decreases with increase of Q
- Sherwood number Sh increases with increase of$Kr, Sc$and decreases with increase of So.

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