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# INDUCED MAGNETIC FIELD AND RADIATION ABSORPTION EFFECTS ON MHD FREE CONVECTIVE CHEMICALLY REACTING FLUID FLOW

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## ABSTRACT

This study is focused on the investigation of magneto hydrodynamic mixed convection radiative heat and mass transfer flow of a steady, viscous, incompressible electrically conducting Newtonian fluid which is an optically thin gray gas over a permeable vertical infinite plate in the presence of first order chemical reaction, temperature gradient heat source, induced magnetic field and magnetic Prandtl number. The governing equations for this flow model are formulated and solved using perturbation technique. The velocity, temperature, concentration and induced magnetic field are studied through graphs, and the skin friction coefficient, Nusselt number and Sherwood number are discussed through tables in detail for different values of physical parameters entering into the problem. It is found that the induced magnetic field increase with magnetic Prandtl number, thermal Grashof number and solutal Grashof number but decrease with thermal radiation, temperature gradient heat source, radiation absorption parameter, Schmidt number and chemical reaction parameter.

**Keywords**: *Induced magnetic field, magnetic Prandtl number, radiation absorption, chemical reaction, MHD.*

## 1. INTRODUCTION

The study of magneto hydrodynamic transport phenomena with induction effects have found increasing applications in many natural and industrial phenomena such as chemical technologies, engineering, geophysics, environments etc. A magnetic field applied to the fluid flow creates electro motive force and changes the velocity distribution. In comparison to an applied magnetic field in the flow direction and applied magnetic field in the transverse direction of the flow acts directly on the velocity of the fluid and may be more active in controlling the flow. However, it increases the drag forces and desires more energy. Several industrial types of equipment such as magneto hydrodynamic generators, pumps, boundary layer controllers and bearings are affected by the interaction between electrical conducting fluid and a magnetic field. The behavior of the flow strongly depends on the orientation and intensity of the applied magnetics. The exerted magnetic field controls the suspended particles and rearranges their concentration in the fluid which strongly changes heat transfer characteristics of the flow. In the fluid the induced magnetic field creates its own magnetic field; hence it can alter the initial magnetic field. An induced magnetic field modifies its original magnetic field as it generates its own magnetic field in the fluid, which modifies the motion of the fluids. Hence in several physical situations it is required to consider. It is also become important due to its industrial applications in many systems and devices, like induction cooking, electric generators, induction welding, wireless energy transfer etc.

Singh et al (2010) discussed induced magnetic field in a vertical channel of electrically conducting fluid. Ahmed (2011) analyzed the impacts of thermal radiation and induced magnetic field on steady convective heat and mass transfer flow of Newtonian fluid by series solution method. Vijaya Kumar et al (2013) investigated the impacts of induced magnetic field and chemical reaction on Newtonian fluid flow with temperature gradient heat source. Authors applied perturbation technique to solve mathematical equations. Suriyakumar and Anjali Devi (2013) analyzed numerically the induced magnetic field and heat sink of a free convection fluid flow between two walls (vertical) with one wall moving. Anand Kumar and Singh (2013) presented the impact of induced magnetic field using implicit Crank-Nicolson method of finite difference on unsteady free convective flow over past a vertical plate. Shakhaoath Khan et al (2014) investigated numerically by Nactsheim-Swigert technique together with 6$^{th}$ order Runge-Kutta technique the mixed convection unsteady flow over an impulsively started porous plate with induced magnetic field, heat generation and time dependent suction. Raju et al. (2015) studied a steady two dimensional MHD Newtonian viscous fluid flow over a vertical porous plate with induced magnetic field. Dipak Sarma and Kamalesh (2015) investigated the laminar flow of viscous electrically conducting fluid under the influence of induced magnetic field over a flat porous plate.

Kibet Kiprop et al (2016) investigated the unsteady MHD Newtonian chemically reacting fluid flow past a vertical plate with porous medium and induce magnetic field using Crank-Nicholson finite difference method. Animasauna et al (2016) studied the impacts of induced magnetic field and nonlinear thermal radiation towards a stagnation point on viscoelastic fluid flow when the diffusion coefficients between the chemical species are unequal. Dileep Kumar and Singh (2016) investigated the effects of radial magnetic field and induced magnetic field with heat source/sink on laminar flow of a viscous incompressible fluid. Jewel Rana et al (2017) analyzed the influence of radiation absorption and variable electrical conductivity on high speed MHD flow past an inclined plate. Venkateswarlu et al (2017) investigated the

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Casson fluid flow over a vertical porous plate with time dependent suction and radiation absorption in the presence of chemical reaction. Dharmaiah et al (2018) analyzed the unsteady, two-dimensional, laminar, boundary layer flow of a viscous incompressible electrically conducting and heat absorbing fluid along a semi-infinite vertical permeable moving plate in the presence of Diffusion-thermo and radiation absorption effects. Basant and Babatunde (2018) studied the induced magnetic field effect on fully developed convection flow in a vertical micro channel with velocity slip, radial magnetic field and temperature jump. Sanjib Sengupta and Amrit Karmakar (2018) examined an analysis of Newtonian electrically conducting chemically reactive fluid in the presence of Darcian porous medium and induced magnetic field. Basant and Babatunde Aina (2018) presented an exact solution for MHD fully developed natural convection viscous, incompressible flow of electrically conducting fluid in micro-channel molded by electrically non-conducting vertical infinite parallel walls in the occurrence of induced magnetic field. The induction and momentum equations are coupled due to induced magnetic field. Odelu Ojjela et al (2019) presented the diffusion thermo and thermo diffusion effects on unsteady 2D incompressible flow of Jeffrey fluid in the occurrence of induced magnetic field and chemical reaction slip flow. In this article authors applied numerical method Runge-Kutta 4$^{th}$ order (shooting) to solve non-linear differential equations. Kumar et al (2019) examined the steady flow of optically thin and conducting fluid with viscous dissipation, induced magnetic field and thermal radiation over a vertical plate. In this flow model applied spectral quasi method to obtain solution of mathematical equations. Sreelatha et al (2020) examined the influence of radiation absorption and chemical reaction effects on unsteady two dimensional fluid flow over a semi-infinite vertical moving porous plate. Jitendra Kumar Singh and Vishwanath et al (2020) studied analytically the flow of electrically conducting viscoelastic fluid in an inclined porous regime channel with induced magnetic field and hall current effects. Rajakumar et al (2020) presented the influence of surface tension and rate of heat transfer in the presence of radiation absorption and ion slip current for Casson fluid past an absorbent vertical plate. Balamurugan et al (2020), studied the temperature gradient heat source and thermal radiation effects on MHD flow with permeable base in the presence of viscous and joules dissipation.

In this study, It is proposed to analyze steady magneto hydro dynamic mixed convection heat and mass transfer flow of a Newtonian, viscous incompressible, electrically conducting radiative fluid past a porous vertical plate in the presence of radiation absorption and chemical reaction taking into consideration the induced magnetic field and a magnetic Prandtl number. The governing equations formulated in this analysis are solved using perturbation technique.

## 2. MATHEMATICAL FORMULATION

In this problem, we study a two dimensional magneto hydro dynamic free convection heat and mass transfer flow of a viscous, incompressible, electrically conducting (Newtonian) fluid over an porous infinite vertical plate with induced magnetic field and radiation absorption in the presence of temperature gradient heat source and a chemical reaction. The $x^*$ - axis is taken along the plate vertically upward direction and $y^*$ - axis is normal to it into the fluid region. It is supposed that the wall is maintained at a fixed temperature $T_w^*$ and concentration $C_w^*$ greater than the ambient temperature $T_\infty^*$ and concentration $C_\infty^*$ respectively. A uniform magnetic field of strength $H_0$ is assumed to be applied normal to the flow direction. We have also made the following assumptions in our investigation to the flow model.

- All the fluid properties are assumed to be constant except the pressure gradient in the body force term.
- There is a chemical reaction between the diffusing species and the fluid.
- The plate is constrained to a constant suction velocity.

Under the Boussinesq approximations along with the above assumptions, the governing equations are

Conservation of Mass:

$$\frac{\partial v^*}{\partial y^*} = 0 \Rightarrow v^* = -v_0 \tag{1}$$

Gauss's law of magnetism:

$$\frac{\partial H_y^*}{\partial y^*} = 0 \Rightarrow H_y^* = H_0 \tag{2}$$

$$v^* \frac{\partial u^*}{\partial y^*} = g\beta(T^* - T_\infty^*) + g\beta^*(C^* - C_\infty^*) + \nu \frac{\partial^2 u}{\partial y^{*2}} + \frac{\mu_e H_0}{\rho}\frac{\partial b_x^*}{\partial y^*} \tag{3}$$

$$v^* \frac{\partial H_x^*}{\partial y^*} = \frac{1}{\rho\mu_e}\frac{\partial^2 H_x^*}{\partial y^{*2}} + \frac{\mu_e H_0}{\rho}\frac{\partial u^*}{\partial y^*} \tag{4}$$

$$\begin{aligned} v^* \frac{\partial T^*}{\partial y^*} &= \frac{k}{\rho c_p}\frac{\partial^2 T^*}{\partial y^{*2}} - \frac{1}{\rho c_p}\frac{\partial q_r}{\partial y^*} + \frac{Q^*}{\rho c_p}\frac{\partial}{\partial y^*}(T^* - T_\infty^*) \\ &\quad - \frac{Ra^*}{\rho c_p}(C^* - C_\infty^*) \end{aligned} \tag{5}$$

$$v^* \frac{\partial C^*}{\partial y^*} = D\frac{\partial^2 C^*}{\partial y^{*2}} - Kr^*(C^* - C_\infty^*) \tag{6}$$

Boundary conditions are

$$\begin{aligned} &y^* = 0: \quad u^* = 0, \quad T^* = T_w^*, \quad C^* = C_w^*, \quad H_x^* = 0 \\ &y^* \to \infty: \quad u^* \to U_0, \quad T^* \to T_\infty^*, \quad C^* \to C_\infty^*, \quad H_x^* \to 0 \end{aligned} \tag{7}$$

The radiant for optically thin gray gas is expressed by

$$\frac{\partial q_r}{\partial y^*} = -4a\alpha^*(T_\infty^{*4} - T^{*4}) \tag{8}$$

Where $T^{*4} = 4T_\infty^3 T^* - 3T_\infty^{*4}$ (9)

Using the equations (8) and (9) and the following non-dimensional quantities (10), the equations (3), (4), (5) and (6) reduce to:

$$\begin{aligned} &y = \frac{v_0 y^*}{\nu}, u = \frac{u^*}{U_0}, \theta = \frac{T^* - T_\infty^*}{T_w^* - T_\infty^*}, \phi = \frac{C^* - C_\infty^*}{C_w^* - C_\infty^*}, B = \frac{H_x^*}{U_0}, \\ &\Pr = \frac{\rho\upsilon c_p}{k}, Q = \frac{Q^*}{\rho v_0 c_p}, Sc = \frac{\upsilon}{D}, Gr = \frac{\upsilon g\beta(T_w^* - T_\infty^*)}{U_0 v_0^{\,2}}, \\ &Gm = \frac{\upsilon g\beta^*(C_w^* - C_\infty^*)}{U_0 v_0^{\,2}}, \Pr m = \rho\upsilon\mu_e, R = \frac{64a\upsilon\alpha^* T_\infty^{*3}}{\rho v_0^{\,2} c_p}, \\ &M = \frac{\mu_e H_0}{\rho v_0}, Kr = \frac{Kr^*\upsilon}{v_0^{\,2}}, Ra = \frac{Ra^* v(C_w^* - C_\infty^*)}{\rho v_0^{\,2} c_p (T_w^* - T_\infty^*)} \end{aligned} \tag{10}$$

Where magnetic parameter-M, Prandtl number-Pr, thermal radiation parameter-R, temperature gradient heat source parameter-Q, radiation absorption parameter-Ra, magnetic Prandtl number-Prm, Schmidt number-Sc, chemical reaction parameter-Kr, thermal Grashof number-Gr, mass Grashof number-Gm

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$$\frac{d^2u}{dy^2}+\frac{du}{dy}+M\frac{dB}{dy}+Gr\theta+Gm\phi=0 \tag{11}$$

$$\frac{d^2B}{dy^2}+M\,\mathrm{Pr}\,m\frac{dB}{dy}+\mathrm{Pr}\,m\frac{dB}{dy}=0 \tag{12}$$

$$\frac{d^2\theta}{dy^2}+\mathrm{Pr}(1+Q)\frac{d\theta}{dy}-\frac{R\,\mathrm{Pr}}{4}\theta=\mathrm{Pr}\,Ra\phi \tag{13}$$

$$\frac{d^2\phi}{dy^2}+Sc\frac{d\phi}{dy}-KrSc\phi=0 \tag{14}$$

The equivalent boundary conditions are:

$$\begin{aligned} y=0: &\quad u=0,\quad \theta=1,\quad \phi=1,\quad B=0 \\ y\to\infty: &\quad u\to 1,\quad \theta\to 0,\quad \phi\to 0,\quad B\to 0 \end{aligned} \tag{15}$$

## 3. SOLUTION OF THE PROBLEM

Solving the equations (13) & (14) subject to the boundary conditions (15), we get

$$\phi=e^{-\lambda y} \tag{16}$$

$$\theta=A_0e^{-\lambda y}+C_2e^{-\xi y} \tag{17}$$

Now to solve the equations (11) & (12) with boundary conditions (15), the perturbation technique is applied.

Let $u(y)=u_0(y)+\varepsilon u_1(y)+O(\varepsilon^2)$

$$B(y)=B_0(y)+\varepsilon B_1(y)+O(\varepsilon^2) \tag{18}$$

Using (18) in equations (11) & (12) and comparing the coefficients of the same degree terms and neglecting higher order terms, we get the following ordinary differential equations

$$u_0''+u_0'+Gr\theta+Gm\phi+MB_0'=0 \tag{19}$$

$$u_1''+u_1'+MB_1'=0 \tag{20}$$

$$B_0''+\mathrm{Pr}\,m\,B_0'+M\,\mathrm{Pr}\,mu_0'=0 \tag{21}$$

$$B_1''+\mathrm{Pr}\,m\,B_1'+M\,\mathrm{Pr}\,mu_1'=0 \tag{22}$$

where the primes denote differentiation with respect to *y*.

The corresponding boundary conditions (15) reduce to:

$$\begin{aligned} y=0: &\quad u_0=0,\quad u_1=0,\quad B_0=0,\quad B_1=0 \\ y\to\infty: &\quad u_0\to 1,\quad u_1\to 0,\quad B_0\to 0,\quad B_1\to 0 \end{aligned} \tag{23}$$

The solutions of (19) – (22) under the boundary condition (23) yield

$$u(y)=A_1e^{-\xi y}+A_2e^{-\lambda y}+A_3e^{-\delta y}+1 \tag{24}$$

$$B(y)=A_4e^{-\delta y}+A_5e^{-\xi y}+A_6e^{-\lambda y}+A_7e^{-\mathrm{Pr}\,m y}+1 \tag{25}$$

### 3.1. Skin Friction:

$$\tau=\left(\frac{\partial u}{\partial y}\right)_{y=0}=-\xi A_1-\lambda A_2-A_3\delta \tag{26}$$

### 3.2. Nusselt Number:

$$Nu=\left(\frac{\partial \theta}{\partial y}\right)_{y=0}=-\lambda A_0-\xi C_2 \tag{27}$$

### 3.3. Sherwood Number:

$$Sh=\left(\frac{\partial \phi}{\partial y}\right)_{y=0}=-\lambda \tag{28}$$

## 4. RESULTS AND DISCUSSION

To get a physical insight into the problem the numerical calculation of the analytical results stated in the previous section was accomplished and a set of results is reported graphically in figures 1-13 for the cooling case Gr > 0 of the plate. These results are attained to illustrate the impacts of different physical parameters like magnetic parameter-M, Prandtl number-Pr, thermal radiation parameter-R, temperature gradient heat source parameter-Q, radiation absorption parameter-Ra, magnetic Prandtl number-Prm, Schmidt number-Sc, chemical reaction parameter-Kr on the velocity, temperature and concentration profiles.

Figure 1 describes the velocity profiles due to variation in magnetic field parameter M for Gr > 0. It is observed that with an increase in M the velocity diminutions for conducting air Pr = 0.71. This is owed to the fact that rising the values of magnetic field parameter, the Lorentz force, which contradicts the flow there is a plummet in velocity utmost due to the retarding result of the magnetic field. The impact of Schmidt number (Sc) and chemical reaction parameter (Kr) on velocity are shown in figure 2. From this figure, it is seen that there is a rise in velocity with increasing values of Sc and Kr. The impact of velocity profile for various values of thermal Grashof number Gr depicted in figure 3. The ratio of the thermal resistance force to the viscous hydrodynamic force acting on a fluid is Grashof number. The negative value of Grashof number aids that the plate is heating and the positive value signifies that the plate is cooling. It is noticed that there is a fall in the velocity of the fluid owing to the increase of thermal resistance force, but near the plate velocity increases as thermal buoyancy increases. The influence of velocity profile for various values of solutal Grashof number Gm depicted in figure 4. The solutal Grashof number Gm describes the fraction of the concentration buoyancy energy to the viscous hydrodynamic force. From this figure it is noticed that there is intensification in the fluid velocity owing to the increase force of species buoyancy. Figure 5 display the effect of magnetic Prandtl number Prm on velocity profile. It is observed that the velocity of the fluid decelerates with magnetic Prandtl number.

The magnetic parameter (M) effect on the induced magnetic field (B) has been presented in figure 6. It is identified that by increase in magnetic effect the induced magnetic field decrease but the trend is reversed near the boundary layer (plate). Figure 7 describe the impact of R-radiation parameter and *Q*-temperature gradient heat source parameter on the induced magnetic field. It is found that induced magnetic field falls with a rise in R or *Q*. Figure 8 portrays on induced magnetic field with the effects of Schmidt number Sc, Chemical reaction parameter Kr and Grashof number Gr. It is noticed that the induced magnetic field decelerates as the Schmidt number Sc or chemical reaction parameter Kr increases, while an increase in Grashof number Gr the induced magnetic field accelerates. Figure 9 describe the influence of radiation absorption parameter Ra and mass Grashof number Gm on induced magnetic field B. It is noticed that induced magnetic field decelerates and accelerates due to increase in radiation absorption parameter Ra and mass Grashof number Gm. Figure 10 shows the effect of magnetic Prandtl number Prm on induced magnetic field B. It is observed that when magnetic Prandtl number Prm rises, the diffusivity of momentum increases, it is the fact that the magnetic field diffused in the medium affecting a corresponding increase in the induced magnetic field magnitudes.

The behavior of fluid temperature by the influence of Prandtl number Pr, radiation absorption parameter Ra, radiation parameter R, temperature gradient heat absorption parameter $Q$, Schmidt number Sc and chemical reaction parameter Kr are shown in figures 11-13. It is seen that with the increase of Prandtl number Pr, radiation absorption parameter Ra, radiation parameter R, temperature gradient heat absorption parameter $Q$ , the fluid temperature decreases whereas Schmidt number Sc and chemical reaction parameter Kr increase the fluid temperature.

Table1 depicts numerical values of the skin friction at boundary layer it is observed that increasing the values of M or Sc or Kr or Pr or R or $Q$ or Ra leads to acceleration in skin friction coefficient while the reverse tendency occur by increasing values of Gr or Gm. In table 2 the impacts of Schmidt number Sc and chemical reaction parameter Kr on the Sherwood number (Sh) are presented. Sherwood number decreases with increasing Sc and Kr.

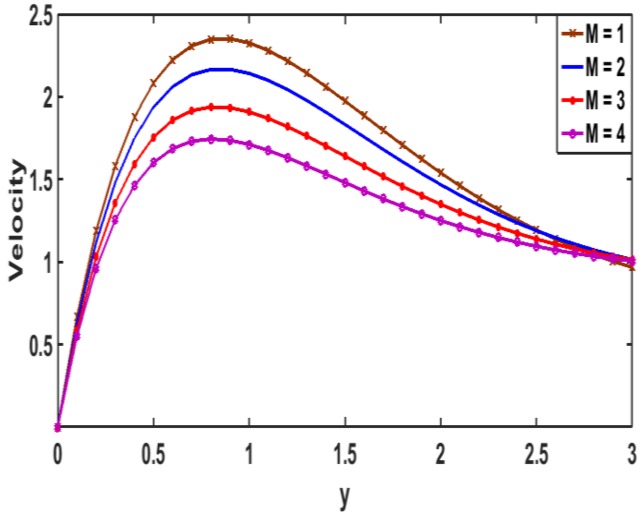


**Fig. 1** Velocity profiles for different values of magnetic parameter

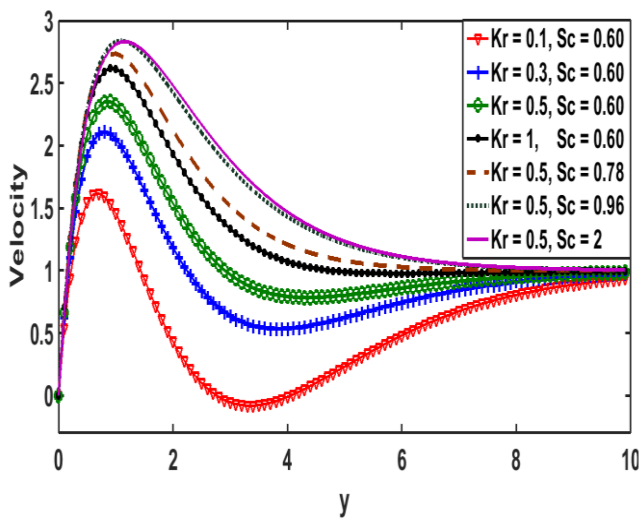


**Fig. 2** Velocity profiles for different values of chemical reaction parameter and Schmidt Number

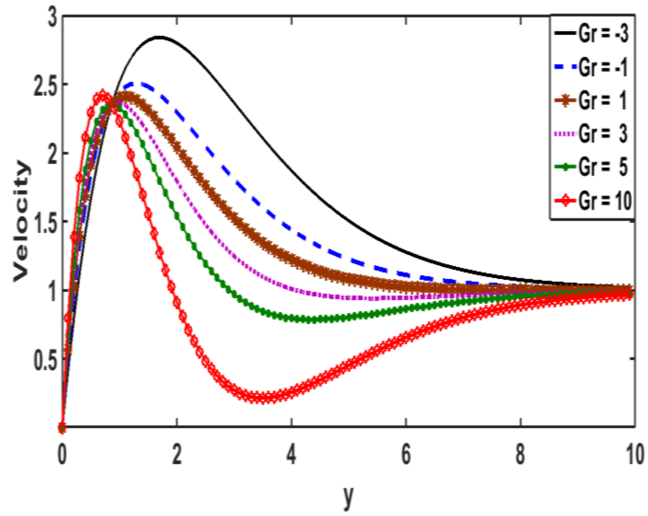


**Fig. 3** Velocity profiles for different values of thermal Grashof number

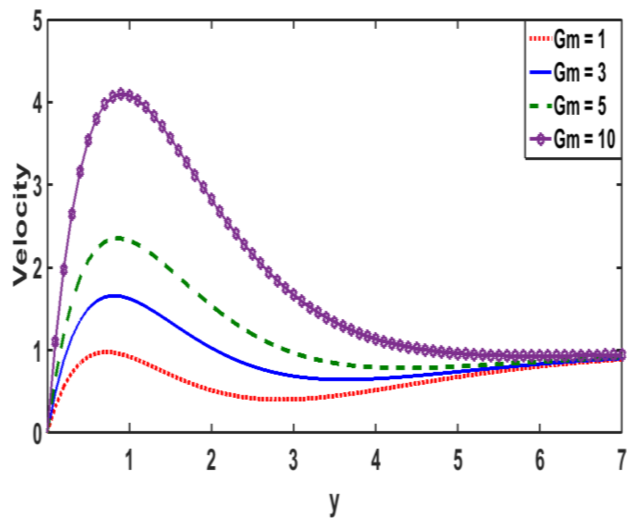


**Fig. 4** Velocity profiles for different values of solutal Grashof number

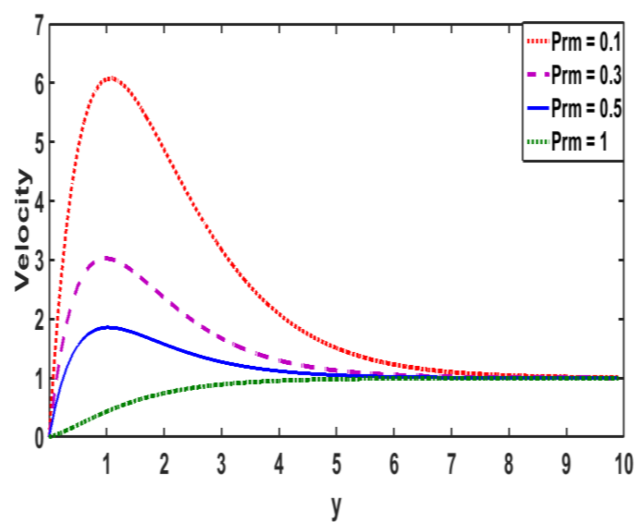


**Fig. 5** Velocity profiles for different values of magnetic Prandtl number

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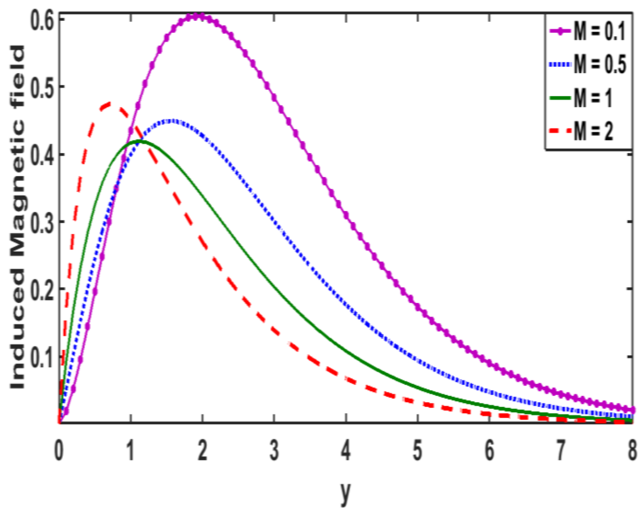


**Fig. 6** Induced magnetic field for different values of M-magnetic parameter

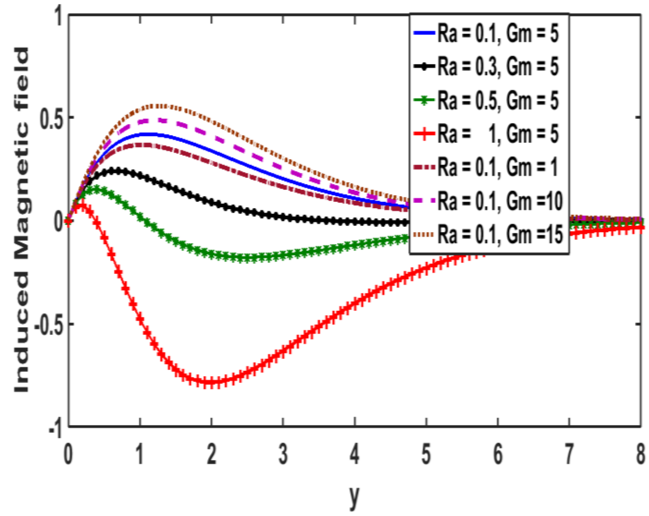


**Fig. 9** Induced magnetic field for different values of radiation absorption parameter and solutal Grashof number

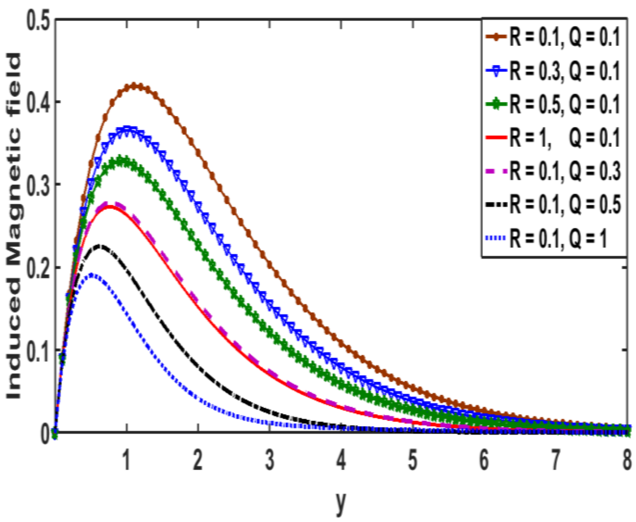


**Fig. 7** Induced magnetic field for different values of radiation and temperature gradient heat absorption parameters

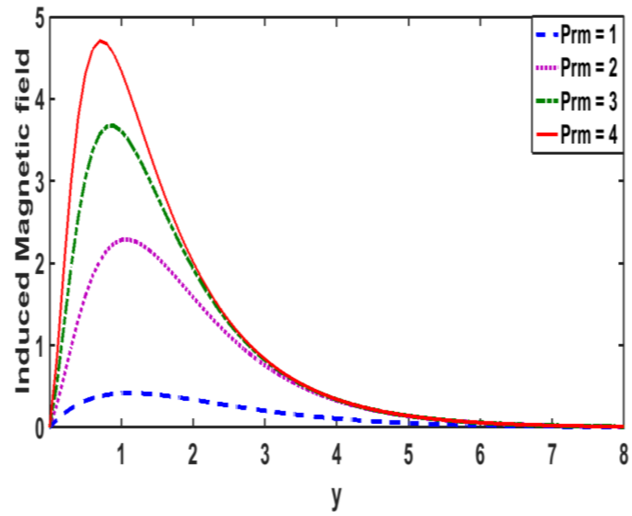


**Fig. 10** Induced magnetic field for different values of magnetic Prandtl number

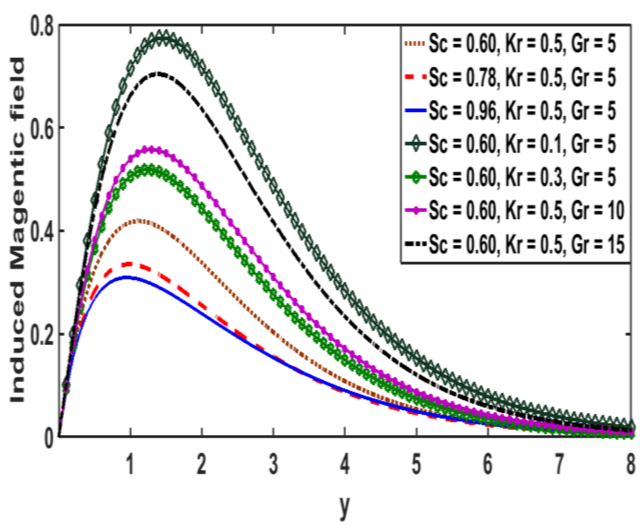


**Fig. 8** Induced magnetic field for different values of Sc, Kr and Gr

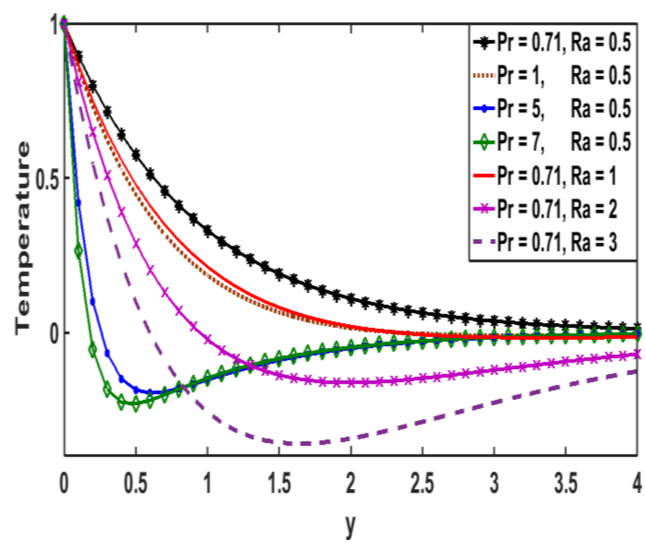


**Fig. 11** Induced magnetic field for different values of Prandtl number and radiation absorption parameter

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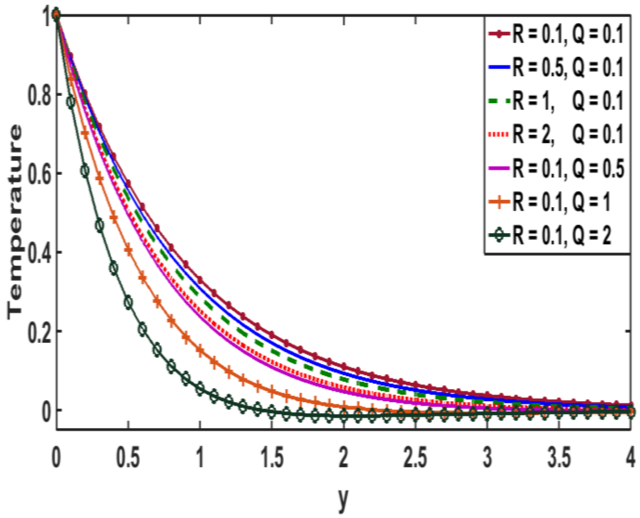


**Fig. 12** Induced magnetic field for different values of radiation parameter and temperature gradient heat absorption parameter

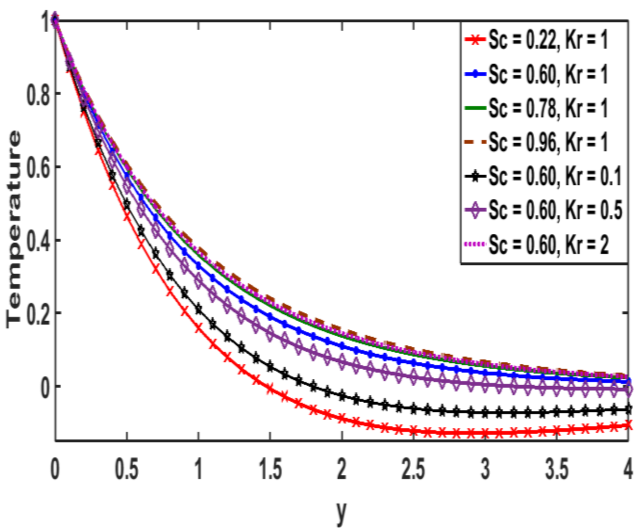


**Fig. 13** Induced magnetic field for different values of Schmidt number and chemical reaction parameter

**Table1**: Skin Friction

| *M* | *Sc* | *Kr* | *Pr* | *R* | *Q* | *Ra* | *Gr* | *Gm* | *Skin Friction* |
|---|---|---|---|---|---|---|---|---|---|
| **1** | **0.60** | **0.5** | **0.71** | **0.1** | **0.1** | **0.1** | **5** | **5** | **0.7021** |
| **2** | 0.60 | 0.5 | 0.71 | 0.1 | 0.1 | 0.1 | 5 | 5 | 2.3969 |
| 1 | **0.78** | 0.5 | 0.71 | 0.1 | 0.1 | 0.1 | 5 | 5 | 1.3585 |
| 1 | **0.96** | 0.5 | 0.71 | 0.1 | 0.1 | 0.1 | 5 | 5 | 1.6447 |
| 1 | 0.60 | **1** | 0.71 | 0.1 | 0.1 | 0.1 | 5 | 5 | 1.3677 |
| 1 | 0.60 | 0.5 | **1** | 0.1 | 0.1 | 0.1 | 5 | 5 | 2.5388 |
| 1 | 0.60 | 0.5 | **2** | 0.1 | 0.1 | 0.1 | 5 | 5 | 3.0690 |
| 1 | 0.60 | 0.5 | 0.71 | **0.5** | 0.1 | 0.1 | 5 | 5 | 1.3136 |
| 1 | 0.60 | 0.5 | 0.71 | **1** | 0.1 | 0.1 | 5 | 5 | 1.7714 |
| 1 | 0.60 | 0.5 | 0.71 | 0.1 | **0.5** | 0.1 | 5 | 5 | 2.2861 |
| 1 | 0.60 | 0.5 | 0.71 | 0.1 | **1** | 0.1 | 5 | 5 | 2.8351 |
| 1 | 0.60 | 0.5 | 0.71 | 0.1 | 0.1 | **0.5** | 5 | 5 | 3.3828 |
| 1 | 0.60 | 0.5 | 0.71 | 0.1 | 0.1 | **1** | 5 | 5 | 6.7338 |
| 1 | 0.60 | 0.5 | 0.71 | 0.1 | 0.1 | 0.1 | **10** | 5 | -0.1541 |
| 1 | 0.60 | 0.5 | 0.71 | 0.1 | 0.1 | 0.1 | **15** | 5 | -1.0103 |
| 1 | 0.60 | 0.5 | 0.71 | 0.1 | 0.1 | 0.1 | 5 | **10** | 0.2604 |

**Table2: Sherwood Number**

| *Sc* | *Kr* | *Sherwood Number* |
|---|---|---|
| 0.22 | 0.5 | -0.459428104193123 |
| **0.60** | **0.5** | **-0.924499799839840** |
| 0.78 | 0.5 | -1.126274405367999 |
| 0.96 | 0.5 | -1.322852300228219 |
| 0.60 | 0.1 | -0.687298334620742 |
| 0.60 | 1.0 | -1.130662386291808 |
| 0.60 | 2.0 | -1.435781669160055 |

In Table3 Nusselt number is examined. From this table it is observed that Nusselt number decreases with an increase in the values of radiation parameter R, Prandtl number Pr, temperature gradient heat source parameter *Q* and radiation absorption parameter Ra, where as it shows opposite phenomenon in the case of Schmidt number Sc and chemical reaction parameter Kr. Lastly, in tables 4 and 5, we accomplished a comparison of our results with those of Vijaya Kumar et al (2013) for velocity and induced magnetic field. It is perceived that the results are in good covenant with their analysis

**Table3**: Nusselt Number

| ***Sc*** | ***Kr*** | ***Pr*** | ***R*** | ***Q*** | ***Ra*** | ***Nusselt Number*** |
|---|---|---|---|---|---|---|
| **0.60** | **0.5** | **0.71** | **0.1** | **0.1** | **1** | **-1.553153354132730** |
| **0.78** | 0.5 | 0.71 | 0.1 | 0.1 | 1 | -1.421366093234063 |
| **0.96** | 0.5 | 0.71 | 0.1 | 0.1 | 1 | -1.331000859507308 |
| 0.60 | **1.0** | 0.71 | 0.1 | 0.1 | 1 | -1.419012678789925 |
| 0.60 | **2.0** | 0.71 | 0.1 | 0.1 | 1 | -1.290109177801151 |
| 0.60 | 0.5 | **1.00** | 0.1 | 0.1 | 1 | -2.178492247790316 |
| 0.60 | 0.5 | **7.00** | 0.1 | 0.1 | 1 | -15.113172390120161 |
| 0.60 | 0.5 | 0.71 | **0.5** | 0.1 | 1 | -1.574235647816874 |
| 0.60 | 0.5 | 0.71 | **1.0** | 0.1 | 1 | -1.605483256932216 |
| 0.60 | 0.5 | 0.71 | 0.1 | **0.5** | 1 | -1.835999536118580 |
| 0.60 | 0.5 | 0.71 | 0.1 | **1.0** | 1 | -2.190216943208072 |
| 0.60 | 0.5 | 0.71 | 0.1 | 0.1 | **2** | -2.303204902646533 |
| 0.60 | 0.5 | 0.71 | 0.1 | 0.1 | **3** | -3.053256451160332 |

**Table4:** Comparison of values of the velocity obtained by Vijayakumar et al. (2013) when Ra = 0

| | *Vijayakumar et al. (2013)* | | | *Present Work* | | |
|---|---|---|---|---|---|---|
| y | R = 0.1 | R = 0.8 | R = 1 | R = 0.1 | R = 0.8 | R = 1 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 3.2584 | 2.6054 | 2.4854 | 3.1985 | 2.5951 | 2.3981 |
| 4 | 1.8523 | 1.5179 | 1.4627 | 1.7611 | 1.4227 | 1.3911 |
| 6 | 1.2406 | 1.1221 | 1.1050 | 1.1701 | 1.0930 | 1.0810 |
| 8 | 1.0613 | 1.0256 | 1.0211 | 1.0591 | 1.0181 | 1.0152 |
| 10 | 1.0149 | 1.0050 | 1.0040 | 1.0085 | 1.0033 | 1.0027 |

**Table5**: Comparison of values of the induced magnetic field obtained by Vijayakumar et al. (2013) when Ra = 0

| | *Vijayakumar et al. (2013)* | | | *Present Work* | | |
|---|---|---|---|---|---|---|
| y | R = 0.1 | R = 0.8 | R = 1 | R = 0.1 | R = 0.8 | R = 1 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | -0.0875 | -0.0637 | -0.0592 | -0.0845 | -0.0597 | -0.0580 |
| 4 | -0.1388 | -0.0969 | -0.0892 | -0.1256 | -0.0935 | -0.0874 |
| 6 | -0.1354 | -0.0916 | -0.0839 | -0.1309 | -0.0882 | -0.0821 |
| 8 | -0.1167 | -0.0777 | -0.0710 | -0.1148 | -0.0760 | -0.0707 |
| 10 | -0.0970 | -0.0642 | -0.0586 | -0.0885 | -0.0594 | -0.0540 |

## 5. CONCLUSIONS

A theoretical investigation is implemented to study the properties of radiation absorption and induce magnetic field on free convection flow of chemically reacting fluid past a vertical plate. The main results are:

- The velocity of the fluid decreases for larger Hartmann number, magnetic Prandtl number and it enhances by mass Grashof number.
- The induced magnetic field is amplified with magnetic Prandtl number Prm.
- An increase in Schmidt number/chemical reaction/thermal radiation/temperature gradient heat source/radiation absorption parameter leads to decelerate the induced magnetic field. Increasing thermal Grashof number/ mass Grashof number the induced magnetic field elevated.
- The fluid temperature is embellishing with Schmidt number and chemical reaction parameter**.**
- The fluid temperature is diminishing with increasing Prandtl number/thermal radiation/temperature gradient heat source/ radiation absorption parameter
- Skin friction is intensely raised by the enhancement of Hartmann number or Prandtl number or thermal radiation parameter or temperature gradient heat source parameter or radiation absorption parameter.
- Under the effect of Prandtl number, thermal radiation, temperature gradient heat source and radiation absorption, the rate of heat transfer reduces.
- The skin friction and Nusselt number increase due to increase in Schmidt number and chemical reaction parameter, while Sherwood number lessening by Schmidt number or chemical reaction parameter.

## NOMENCLATURE

| | |
|---|---|
| $H_0$ | Externally applied transverse magnetic field |
| $x^*, y^*$ | Coordinate system |
| $k$ | Thermal conductivity |
| $M$ | Magnetic parameter |
| $q_r$ | Radiative heat flux |
| $R$ | Thermal radiation parameter |
| $T^*$ | Temperature |
| $T_w^*$ | Temperatures of the fluid at the surface |
| $T_\infty^*$ | Temperatures of the fluid in the free stream |
| $Q$ | Temperature gradient heat source parameter |
| $u$ | Velocity component in x-direction |
| $U_0$ | Dimensionless free stream velocity |
| $C^*$ | Species concentration |
| $C_\infty^*$ | Species concentration in the free stream |
| $C_w^*$ | Species concentration at the surface |
| D | Chemical molecular diffusivity |
| $g$ | Acceleration due to gravity |
| $Gr$ | Thermal Grashof number |
| $Gm$ | Mass Grashof number |
| $a$ | Absorption coefficient |
| $Kr$ | Chemical reaction parameter |
| $Ra$ | Radiation absorption parameter |
| $c_p$ | Specific heat at constant pressure |
| Pr | Prandtl number |
| Prm | Magnetic Prandtl number |
| Sc | Schmidt number |
| $\tau$ | Skin friction coefficient |
| $Nu$ | Nusselt number |
| $Sh$ | Sherwood number |

*Greek Symbols*

| | |
|---|---|
| $\beta$ | Coefficient of Volume expansion for heat transfer |
| $\beta^*$ | Coefficient of Volume expansion for mass transfer |
| θ | Fluid temperature |
| $\phi$ | Fluid concentration |
| $\rho$ | Density |
| $\mu$ | Dynamic viscosity |
| $\sigma$ | Electric conductivity |

*Superscripts*

| | |
|---|---|
| * | Dimensional parameters |

## REFERENCES

Singh, R.K.,. Singh, A.K., Sacheti, N.C., and Pallath Chandran, 2010, "on hydro magnetic free convection in the presence of induced magnetic field", *Heat Mass Transfer*, 46, 523-569. https://doi.org/10.1007/s00231-010-0594-6.

Ahmed, S., 2011, "A study of induced magnetic field with chemically reacting and radiating fluid past a vertical permeable plate", *Journal of Engineering Physics and Thermo Physics*, 84, 1360-1368. https://doi.org/10.1007/s10891-011-0606-5.

Vijaya Kumar, A.G., B. Rushi Kumar, B., Balamurugan K.S. and Varma, S.V.K., 2013, "The effects of induced magnetic field and radiation on MHD mixed convective chemically reacting fluid over a porous vertical plate", *Far East Journal of Mathematical Sciences*, 80(1), 135-154..

Suriyakumar, P., and Anjali Devi, AP., 2013, "Transient free convection MHD flow between two vertical walls with one wall moving in the presence of induced magnetic field and heat sink", *Research Journal of Science and Technology*, 5(1), 198-206.

Anand Kumar and Singh, A.K., 2013, "Unsteady MHD free convective flow past a semi-infinite vertical wall with induced magnetic field", *Applied Mathematics and Computation*, 222(1), 462-471. https://doi.org/10.1016/j.amc.2013.07.044.

Md. Shakhaoath Khan, Mohammad Wahiduzzaman., Md. Ifsana Karima. Sirajul Islam, and Md. Mahamud Alam, 2014, "Heat generation effects on unsteady mixed convection flow from a vertical porous plate with induced magnetic field", *Procedia Engineering*, 90, 238-244. https://doi.org/10.1016/j.proeng.2014.11.843.

Raju, M.C., Varma, S.V.K., and Seshaiah, B., 2015, "Heat transfer effects on a viscous dissipative fluid flow past a vertical plate in the presence of induced magnetic field", *Ain Shams Engineering Journal*, 6, 333-339. https://dx.doi.org/10.1016/j.asej.2014.07.009.

Dipak Sarma and Kamalesh Pandit., K., 2015, "Effects of thermal radiation and chemical reaction on steady MHD fixed convective flow over a vertical porous plate with induced magnetic field", *International Journal of Fluid Mechanics Research*, 42(15), 315-333. https://doi.org/10.1615/InterJFluidMechRes.v42.i4.30.

Kibet Kiprop, Mathew Ngugi Kinyanjui., and Jackson Kioko Kwanza., 2016, "Hydrodynamic radiating fluid flow past an infinite vertical porous plate in presence of chemical reaction and induced magnetic field", *American Journal of Applied Mathematics*, 4(2), 62-74. https://doi.org/10.11648/j.ajam.20160402.11.

Animasauna, I.L., Raju, C.S.K., and Sandeep, N., 2016, "Unequal diffusivities case of homogeneous-heterogeneous reactions with in visco elastic fluid flow in the presence of induced magnetic field and nonlinear thermal radiation", *Alexandria Engineering Journal*, 55, 1595-1606. https://dx.doi.org/10.1016/j.aej.2016.01.018.

Dileep Kumar and Singh, A.K., 2016, "Effects of heat source/sink and induced magnetic field on natural convective flow in vertical concentric

DOI: 10.5098/hmt.18.21
ISSN: 2151-8629

annuli", *Alexandria Engineering Journal*, 55, 3125-3133. https://dx.doi.org/10.1016/j.aej.2016.08.019.

Jewel Rana, B.M., Raju Roy, Lasker Ershad Ali., and Ahmmed, S.F., 2017, "Radiation absorption and variable electrical conductivity effect on high speed MHD free convective flow past an exponential accelerated inclined plate", *World Journal of Mechanics*, 7, 211-241. https://doi.org/10.4236/wjm.2017.78019.

Venkateswarlu, S., Varma, S.V.K., Kiran Kumar, R.V.M.S.S., Chakravarthula, S.K.R., and Putta Durga Prasad., 2017, "Radiation absorption and viscous dissipation on MHD flow of Casson fluid over a vertical plate filled with porous layers", *Diffusion Foundations*, 11, 43-56.
https://doi.org/10.4028/www.scientific.net/DF.11.43.

Dharmaiah. G, Baby Rani, Ch, Vedavathi, N., and Balamurugan. K.S., 2018, "Heat and Mass Transfer on MHD fluid flow over a semi-infinite flat plate with radiation absorption, heat source and diffusion thermo effect", *Frontiers in Heat and Mass Transfer*, 11, 6, 1-8. https://doi.org/10.5098/hmt.11.6.

Basant Jha, K., and Babatunde Aina., 2018, "Impact of induced magnetic field on magneto hydrodynamic (MHD) natural convection flow in a vertical annual micro channel in the presence of radial magnetic field", *Propulsion and Power Research*, 7(2), 171-181. https://doi.org/10.1016/j.jppr.2018.04.004.

Sanjib Sengupta and Amrit Karmakar., 2018, "Induced magnetic field interaction in free convective heat and mass transfer flow of a chemically reactive heat generating fluid with thermo diffusion and diffusion thermo effects", *Frontiers in Heat and Mass Transfer*, 10, 19, 1-12. https://doi.org/10.5098/hmt.10.19.

Basant Jha., K., and Babatunde Aina., 2018, "Interplay of non-conducting and conducting walls on magneto hydrodynamic (MHD) natural convection flow in vertical micro channel in the presence of induced magnetic field", *Propulsion and Power Research*, 7(4), 296-307. https://doi.org/10.1016/j.jppr.2018.07.006.

Odelu Ojjela, Adigoppula Raju and N. Naresh Kumar, N, 2019, "Influence of induced magnetic field and radiation on free convective Jeffrey fluid flow between two parallel porous plates with soret and dufour effects", *Journal of Mechanics*, 35(5), 657-675. https://doi.org/10.1017/jmech.2018.68.

Kumar, B., Seth, G.S., Nandkeolyar R., and Chamkha, A.J., 2019, "Out lining the impact of induced magnetic field and thermal radiation on magneto convection flow of dissipative fluid", *International Journal of Thermal Sciences*, 146, 106101.
https://doi.org/10.1016/i.ijthermalsci.2019.106101.

Sreelatha, S., Balamurugan, K.S., and Rajakumar, K.V.B., 2020, " Heat and Mass Transfer effects on MHD free convection flow past a semi-infinite vertical permeable moving plate with radiation absorption and chemical reaction", *Journal of Advanced Research in Dynamical & Control Systems*, 12(2), 1508-1520.
https://doi.org/10.5373/JARDCS/V1212/20201192.

Jitendra Kumar Singh and Vishwanath, S., 2020, "Hall and induced magnetic field effects on convective flow of viscoelastic fluid with in an inclined channel with periodic surface conditions", *International Journal of Thermo fluid Science and Technology*, 7(4), 070402, 1-20. https://doi.org/10.36963/IJTST.2020070402.

Rajakumar, K.V.B., Pavan Kumar Rayaprolu, V.S.R., Balamurugan K.S., and Bharat Kumar, V., 2020, "Unsteady MHD Casson dissipative fluid flow past a semi-infinite vertical porous plate with radiation absorption and chemical reaction in presence of heat generation", *Mathematical Modelling of Engineering Problems*, 7(1), 160-172. https://doi.org/10.18280/mmep.070120.

Balamurugan, K.S., Udaya Bhaskara Varma, N., and Ramaprasad, J.L., 2020, "Entropy Generation and Temperature gradient heat source effects on MHD couette flow with permeable base in the presence of viscous and joules dissipation", *Frontiers in Heat and Mass Transfer*, 15, 8, 1-7.
https://doi.org/10.5098/hmt.15.8.