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MHD Heat and Mass Transfer Steady Flow of a Convective Fluid Through a Porous Plate in the Presence of Multiple Parameters Along with Dufour Effect

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ABSTRACT

The study of chemical effect, heat source/sink, and Joule effect on heat transfer and mass transfer (HAMT) in Magneto hydrodynamics (MHD) mixed convection flow through an infinite vertical plate along with viscous dissipation and ohmic heating is of greater importance now-a-days and has been examined. The aim of the current work is to include Dufour effect and to study its result along with various parameters. The emphasis is on the flow of a viscous, electrically conducting and incompressible fluid which is mixed convective liquid. The x-axis is chosen along the plate in vertical direction and y-axis is perpendicular to x-axis. A crosswise magnetic field is enforced in the direction of y-axis in a constant manner. For flow on the cooled plate for which "Gr" is greater than 0, and for flow on the heated plate for which "Gr" is lesser than 0, the fluid velocity, fluid temperature and fluid concentration profiles are compared between air (Pr = 0.71) and water (Pr = 7). In the current study, the concurrent occurrence of radiation, heat absorption and dufour effect in the magnetic field has been considered. The numerical solution obtained by software system Matlab and the analytic solution obtained by Perturbation method are studied.

1. INTRODUCTION

The simultaneous occurrence of HAMT in a flowing fluid, affecting each other creates a cross diffusion effect. The transfer of mass acquired by temperature gradient is termed as Soret effect. The transfer of heat caused by concentration effect is called as Dufour effect. Dufour and Soret effects are important phenomena in hydrology, geosciences and petrology. Diffusion is the net movement of an object from a higher concentration area to a lower concentration area. Distribution is regulated by a concentration curve. Numerous disciplines, including physics (more precisely, diffusion), chemistry, genetics, economics, and finance, regularly employ the diffusion idea. Chemical reactors are the primary focus of chemical reaction engineering, a subfield of industrial chemistry or chemical engineering. The expression frequently only refers to catalytic reaction systems when a homogeneous or heterogeneous catalyst is present in the reactor. Examples include photo catalytic surfaces, reactive separations, containers, retorts, certain fuel cells, and so forth. Additionally, it is believed that the subject of solvent effects on kinetic parameters is vital. Reactors are built using principles from several different scientific disciplines, including thermodynamics, chemical kinetics, fluid mechanics, heat and mass transport, and economics. Chemical reaction engineering seeks to synthesize each of these components in order to successfully build a chemical reactor. According to Srinivas Reddy [1], thermal diffusion and diffusion thermo effects were taken into account when analyzing the effect of chemical reactions on MHD free convection HAMT from vertical surfaces in porous media. Effects of diffusion-thermo and chemical reactions on an unstable MHD free convection flow in a micropolar fluid were examined by Sheri and Shamshuddin [2]. Krishna Murthy and Kumar [3] studied the MHD double diffusive free convection operation in addition to a normal "wavy surface embedded in a doubly stratified, fluid-saturated medium that is porous in nature after learning the results of Dufour and Soret effect" [3]. Umamaheshwar et al. [4] carefully observed the impact of chemicals on MHD fluid flow that is doubly diffusive past a rotating porous plate. Agarwalla and Ahmed [5] looked into the MHD transfer of mass flow via an inclined plate that is embedded in a penetrable medium and has variable velocity and temperature. Lorenzini et al. [6] examined MHD HAMT steady flow of a convective fluid past a permeable plate in the existence of various parameters. Kafoussias and Williams [7] investigated the impact of diffusion-thermo and thermal diffusion on mixed free-forced convective and mass transfer boundary layer flow with temperature-dependent viscosity in light of the significance of the diffusion-thermo effect. Raju et al. [8] have conducted a thorough investigation on MHD fluid with visco-elastic flow across a limitless perpendicular plate while taking into account chemical reaction and radiation reaction. Seth et al. [9] reveals the theoretical analysis of convective fluid flow under thermal diffusion, heat increase and MHD transfer in a conducting field. Krishna Murthy et al. [10] used soret and dufour effects to analyse the HAMT in two dimensional MHD free convective boundary layer flow along a straight semi infinite flat surface submerged in a thermally and mass stretched Darcy porous media. Ibrahim [11] investigated the influence of thermal radiation, heat generation and chemical reaction on unstable free convection on the unsteady free convection flow of viscous incompressible fluid through a porous medium with high porosity that is contained by a perpendicular endless moving plate. Postelnicu [12] studied the dufour and soret effects on the properties of natural convection around a vertical plane contained in a saturated porous media exposed to a magnetic field.

In the presence of a magnetic field, there are numerous instruments that measure thermal energy diffusion through mercury, electrolyte liquids, water, and air as well as absorption, thermal diffusivity and chemical effects. The effects of mass and heat transfer of a natural convection fluid flow through a plate that is porous in nature are therefore suggested to be studied in this work in the appearance of various parameters along with Dufour effect.

2. MATHEMATICAL FORMULATION

In this present problem, the fluid under consideration is viscous, incompressible, radiating in nature and electrically conducting that progress through a permeable medium in a space especially semi-infinite which is bordered by an erect and infinite surface. The x-axis is in a rising direction and normal to it is the y-axis. A uniform magnetic field, radiation and Joule heating are imposed transversely along y-axis. The properties of the fluid are supposed to be fixed keeping its density factored out in the term that involves body force. Species of chemically reactive quality are thought of to be secreted from the surface toward a hydrodynamic field where they diffuse into the liquid and undergo a chemically homogenous reaction. Throughout in the stream, the reaction is assumed to take place.

3. PHYSICAL MODEL OF THE PROBLEM

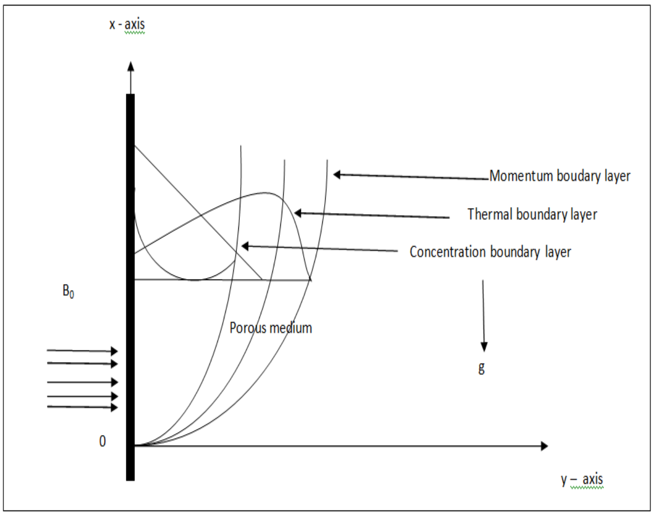

Figure 1. Configuration of the problem

The flow past a porous medium is governed by the consequent equations:

Eq. (1) implies Equation of Continuity: $\nabla . v = 0$, (since fluid is incompressible).

Eq. (2) is Equation of Motion.

Eq. (3) implies Equation of Energy.

Eq. (4) shows Equation of Mass transfer.

$$\frac{\partial v'}{\partial y'} = 0 \tag{1}$$

$$\begin{aligned} v'\frac{\partial u'}{\partial y'} &= \nu\frac{\partial^2 u'}{\partial y'^2} + g\beta\left(T' - T_\infty'\right) + g\beta * \left(C' - C_\infty'\right) \\ &- \frac{\sigma {B_0}^2}{\rho}u' - \frac{\nu u'}{K_p} - \frac{\partial p}{\partial x}\left(\frac{1}{\rho}\right) \end{aligned} \tag{2}$$

$$\begin{aligned} v'\frac{\partial T'}{\partial y'} &= \frac{k}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} + \frac{\nu}{C_p}\left(\frac{\partial u'}{\partial y'}\right)^2 - \frac{1}{\rho C_p}\frac{\partial q_r'}{\partial y'} \\ &+ \frac{\sigma {B_0}^2}{\rho C_p}u' - \frac{Q_1}{\rho C_p}\left(T' - T_\infty'\right) + \frac{D_{K_t}}{\rho C_p C_s}\frac{\partial^2 C'}{\partial y'^2} \end{aligned} \tag{3}$$

$$v'\frac{\partial C'}{\partial y'} = D\frac{\partial^2 C'}{\partial y'^2} - K\left(C' - C_\infty'\right) \tag{4}$$

The boundary conditions (B.C) are:

$$\begin{aligned} &u' = 0, T' = T_w, C' = C_w at y' = 0 \\ &u' \to 0, T' \to T_\infty, C' \to C_\infty as y' \to \infty \end{aligned} \tag{5}$$

The Eq. (1) shows,

$$v' = \text{constant} = -v_0\,(v_0 > 0) \tag{6}$$

The dimension-less quantities are as mentioned below:

$$\begin{aligned} &u = \frac{u'}{v_0}, y = \frac{v_0 y'}{\nu}, \theta = \frac{T' - T_\infty'}{T_w - T_\infty'}, \varphi = \frac{C' - C_\infty'}{C_w - C_\infty'}, \\ &Pr = \frac{\mu C_p}{K}, Sc = \frac{\nu}{D}, M = \frac{\sigma {B_0}^2 \nu}{\rho {v_0}^2}, \\ &Gr = \frac{\nu g\beta\left(T_w - T_\infty'\right)}{{v_0}^3}, Gm = \frac{\nu g\beta * \left(C_w - C_\infty'\right)}{{v_0}^3}, \\ &E = \frac{{v_0}^2}{C_p\left(T_w - T_\infty'\right)}, K = \frac{{v_0}^2 K_p}{\nu^2}, K_0 = \frac{\nu Kc}{{v_0}^2}, \\ &F = \frac{4I_1\nu^2}{K{v_0}^2}, Q = \frac{Q_1\nu^2}{K{v_0}^2}, D_f = \frac{D_{KT}\left(C_w - C_\infty'\right)}{C_s\nu\left(T_w - T_\infty'\right)} \end{aligned} \tag{7}$$

The dimension less form of the governing Eqns. (2)-(4) are written in the following form as:

$$u'' + u' = -Gr\theta - Gm\varphi + M_1 u \tag{8}$$

$$\begin{aligned} \theta'' + Pr\,\theta' - (F + Q)\theta &= -Pr\,u'^2\,E - Pr\,M\,u^2 E \\ &+ Df\,\varphi''\,Pr \end{aligned} \tag{9}$$

$$\varphi'' + Sc\varphi' - ScK_0\varphi = 0 \tag{10}$$

where, $M_1 = M + {}^{1}/_{K}$.

B.C are:

$$\begin{aligned} &u = 0, \theta = 1, \varphi = 1 at y = 0 \\ &u \to 0, \theta \to 0, \varphi \to 0.5 as y \to \infty \end{aligned} \tag{11}$$

4. SOLUTION OF THE PROBLEM

The Eqns. (8)-(10) are solved with B.C (11) by simple perturbation method. The governing Eqns. (8)-(10) expanded in terms of powers of “E” whose value is very small.

$$\begin{aligned} &u = u_0 + Eu_1 + O(E^2) \\ &\theta = \theta_0 + E\theta_1 + O(E^2) \\ &\varphi = \varphi_0 + E\varphi_1 + O(E^2) \end{aligned} \tag{12}$$

On substituting the Eq. (12) into Eqns. (8)-(10) and expanding by neglecting the higher powers of "E", the following equations are obtained by equating the like terms.

Zero order terms:

$$u_0{}'' + u_0{}' = -Gr\theta_0 - Gm\varphi_0 + M_1 u_0 \tag{13}$$

$$\theta_0{}'' + Pr\,\theta_0{}' - (F+Q)\theta_0 = Df\varphi_0{}''\,Pr \tag{14}$$

$$\varphi_0{}'' + Sc\varphi_0{}' - ScK_0\varphi_0 = 0 \tag{15}$$

First order terms:

$$u_1{}'' + u_1{}' = -Gr\theta_1 - Gm\varphi_1 + M_1 u_1 \tag{16}$$

$$\begin{aligned}&\theta_1{}'' + Pr\,\theta_1{}' - (F+Q)\theta_1 = -Pr\,u_0{}'^2 - Pr\,M\,u_0{}^2\\ &+Df\,Pr\,\varphi_1{}''\end{aligned} \tag{17}$$

$$\varphi_1{}'' + Sc\varphi 1' - ScK_0\varphi 1 = 0 \tag{18}$$

B.C are:

$$\begin{aligned}&u_0 = 0, u_1 = 0, \theta_0 = 1, \theta_1 = 0, \varphi_0 = 1, \varphi_1\\ &\qquad = 0.5 at y = 0\\ &u_0 \to 0, u_1 \to 0, \theta_0 \to 1, \theta_1 \to 0, \varphi_0 \to 1, \varphi_1 \to 0\\ &as y \to \infty\end{aligned} \tag{19}$$

By using the boundary conditions in Eq. (19), the Eqns. (13)-(18) are solved and the equations mentioned below are obtained.

$$\varphi_0 = e^{m_2 y} \tag{20}$$

$$\theta_0 = B_2 e^{m_4 y} + C_2 e^{m_2 y} \tag{21}$$

$$u_0 = B_3 e^{m_6 y} - C_3 e^{m_4 y} - (D_3 + E_3)e^{m_2 y} \tag{22}$$

$$\varphi_1 = (0.5)e^{m_8 y} \tag{23}$$

$$\begin{aligned}&\theta_1 = B_6 e^{m10y} - H_1 e^{2m_6 y} - H_2 e^{2m_4 y} - H_3 e^{2m_2 y}\\ &+H_4 e^{(m_4+m_6)y} + H_5 e^{(m_6+m_2)y} - H_6 e^{(m_4+m_2)y}\\ &+H_{11} e^{m_8 y}\end{aligned} \tag{24}$$

$$\begin{aligned}&u_1 = B_7 e^{m_{12} y} - S_1 e^{m_{10} y} - S_2 e^{2m_6 y} - S_3 e^{2m_4 y}\\ &\qquad - S_4 e^{2m_2 y}\\ &+S_5 e^{\delta_1 y} + S_6 e^{\delta_2 y} - S_7 e^{\delta_3 y} - S_8 e^{m_8 y} - S_9 e^{m_8 y}\end{aligned} \tag{25}$$

On substituting the Eqns. (20)-(25) in the Eq. (12), we get the velocity (u), temperature (θ) and concentration field (φ) as mentioned below:

$$\begin{aligned}&u = B_3 e^{m_6 y} - C_3 e^{m_4 y} - (D_3 + E_3)e^{m_2 y}\\ &+E\begin{pmatrix}B_7 e^{m_{12} y} - S_1 e^{m_{10} y} - S_2 e^{2m_6 y} - S_3 e^{2m_4 y}\\ -S_4 e^{2m_2 y} + S_5 e^{\delta_1 y} +\\ S_6 e^{\delta_2 y} - S_7 e^{\delta_3 y} - S_8 e^{m_8 y} - S_9 e^{m_8 y}\end{pmatrix}\end{aligned} \tag{26}$$

$$\begin{aligned}&\theta = B_2 e^{m_4 y} + C_2 e^{m_2 y}\\ &+E\begin{pmatrix}B_6 e^{m10y} - H_1 e^{2m_6 y} - H_2 e^{2m_4 y} - H_3 e^{2m_2 y} +\\ H_4 e^{(m_4+m_6)y} + H_5 e^{(m_6+m_2)y}\\ -H_6 e^{(m_4+m_2)y} + H_{11} e^{m_8 y}\end{pmatrix}\end{aligned} \tag{27}$$

$$\varphi = e^{m_2 y} + E((0.5)e^{m_8 y}) \tag{28}$$

Skin Friction (SF):

The skin friction at the surface is obtained by

$$\begin{aligned}&\tau = \left(\frac{\partial u}{\partial y}\right)_{y=0}\\ &\tau = [B_3 m_6 - C_3 m_4 - (D_3 + E_3)m_2]\\ &+E\begin{bmatrix}B_7 m_{12} - S_1 m_{10} - S_2(2m_6) - S_3(2m_4)\\ -S_4(2m_2) + S_5\delta_1 + S_6\delta_2 - S_7\delta_3\\ -S_8 m_8 - S_9 m_8\end{bmatrix}\end{aligned} \tag{29}$$

Nusselt Number (Nu):

The heat transfer rate by means of Nusselt number, is got by

$$\begin{aligned}&Nu = -\left(\frac{\partial\theta}{\partial y}\right)_{y=0}\\ &Nu = -\left\{\begin{matrix}[B_2 m_4 + C_2 m_2]\\ +E\begin{bmatrix}B_6 m_{10} - 2H_1 m_6 - 2H_2 m_4\\ -2H_3 m_2 + (m_6 + m_4)H_4\\ +(m_6 + m_2)H_5 - (m_4 + m_2)H_6\\ +H_{11} m_8\end{bmatrix}\end{matrix}\right\}\end{aligned} \tag{30}$$

5. RESULTS AND DISCUSSION

In this work, a detailed study in velocity, temperature and concentration field concerning to the effects of MHD convective flow on HAMT of a viscous, conducting, incompressible fluid through a porous and infinite plate is considered. Along with this, the effects of magnetic field, radiation, chemical effects and absorption are also taken into account. Two versions of 'Gr' are presented numerically during heating and cooling of the plate. The Prandtl number (Pr) values are chosen as 0.025, 0.71, 1 and 7, which imply mercury, air, electrolytic friction, water, heat and mass transfer respectively. At 20°C temperature, 1 atmospheric pressure and at the choice of Eckert number as 0.02 the mercury level is taken into consideration. The values of Schmidt number Sc are taken to be 0.22, 0.30, 0.60 and 0.78 that represents hydrogen, helium, water vapour and ammonia respectively. The values Gr=5, Gm=5, K_0=1, K=1, M=2, F=1, Q=1 is chosen for consideration. By the aid of following figures, the obtained results are explained.

On choosing different values of the parameters, the outcome of parameters on velocity, temperature and concentration can be studied. The influence of parameters on SF and Nusselt number are given in Tables 1 and 2.

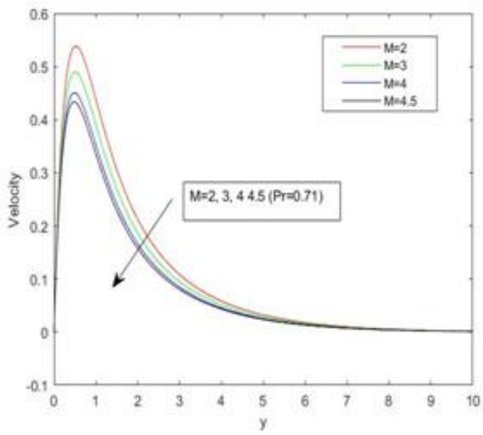

Figure 2. Mon VP (Gr=5)

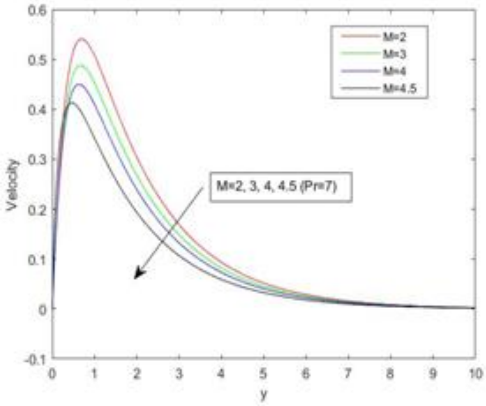

Figure 3. M on VP (Gr=-5.0)

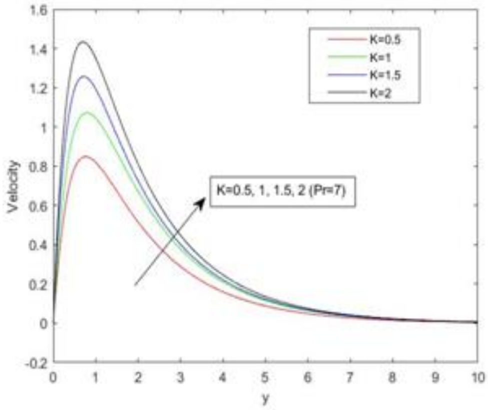

Figure 7. K on VP (Gr=-5.0)

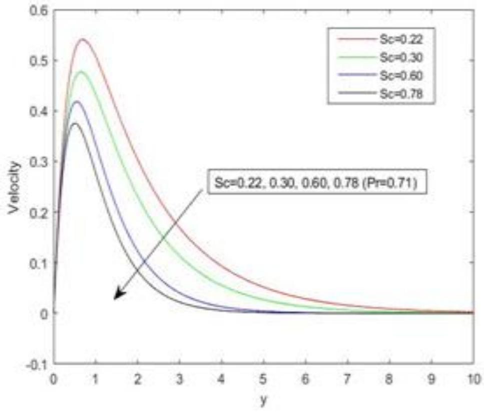

Figure 4. Sc on VP (Gr=5)

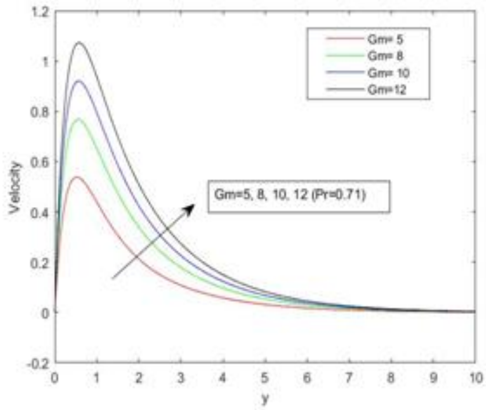

Figure 8. Gm on VP (Gr=5)

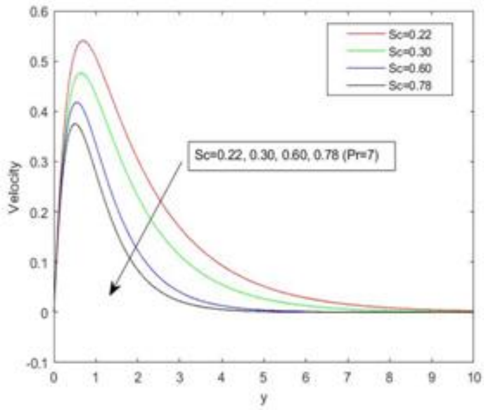

Figure 5. Sc on VP (Gr=-5.0)

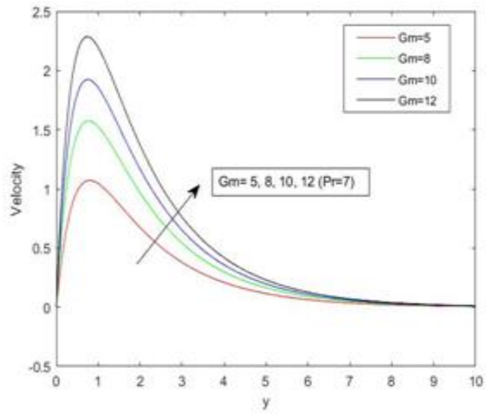

Figure 9. Gm on VP (Gr=-5.0)

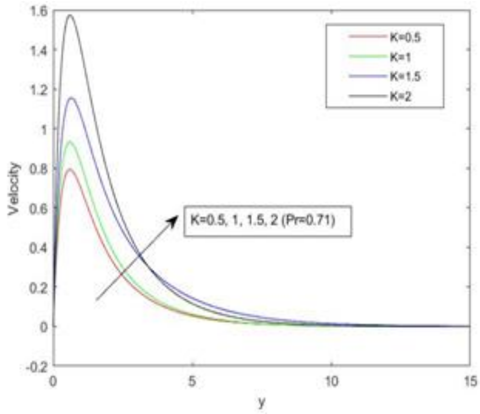

Figure 6. K on VP (Gr=5)

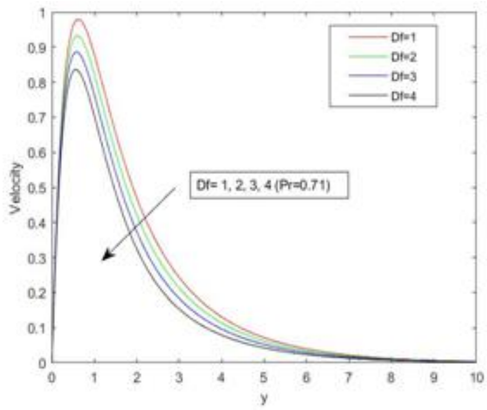

Figure 10. Df on VP (Gr=5)

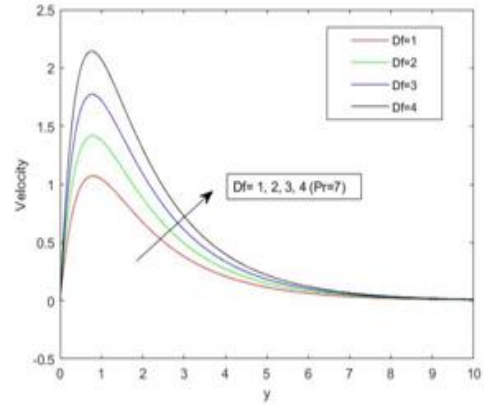

Figure 11. Df on VP (Gr=-5.0)

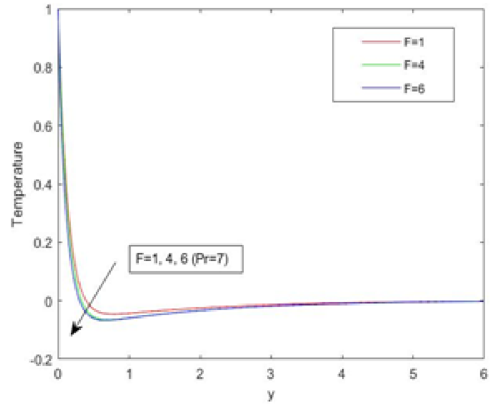

Figure 15. F on TP (Gr=-5.0)

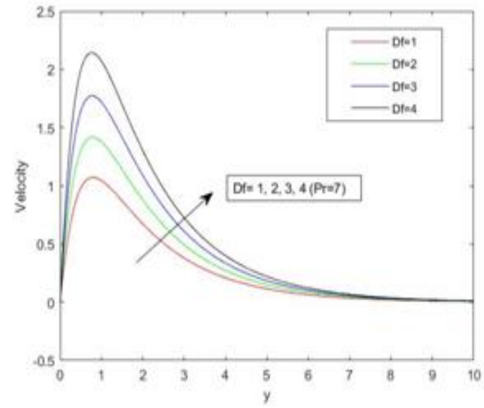

Figure 12. Pr on TP (Gr=5)

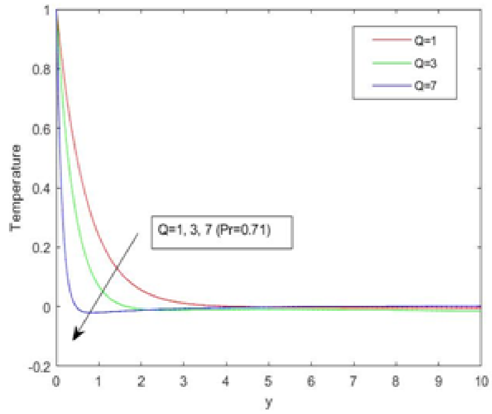

Figure 16. Q on TP (Gr=5)

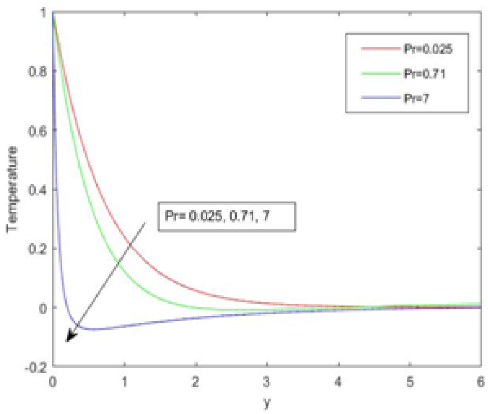

Figure 13. Pr on TP (Gr=-5.0)

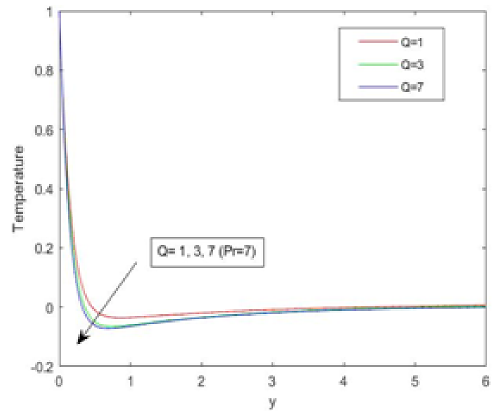

Figure 17. Q on TP (Gr=-5.0)

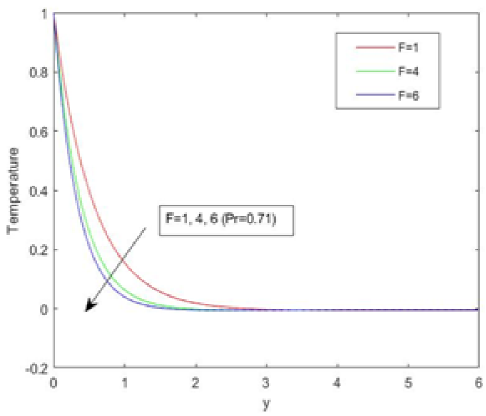

Figure 14. F on TP (Gr=5)

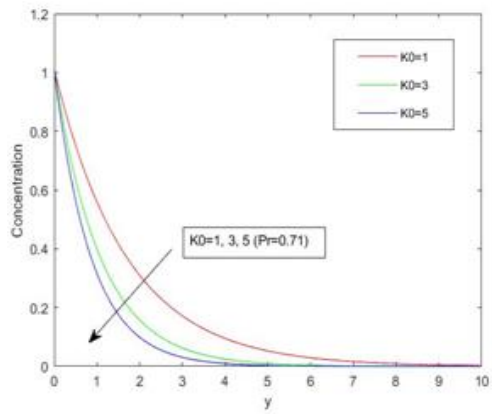

Figure 18. K_0 on CP (Gr=5)

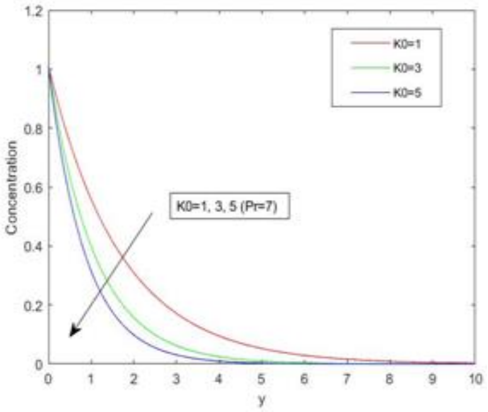

Figure 19. K_0 on CP (Gr=-5.0)

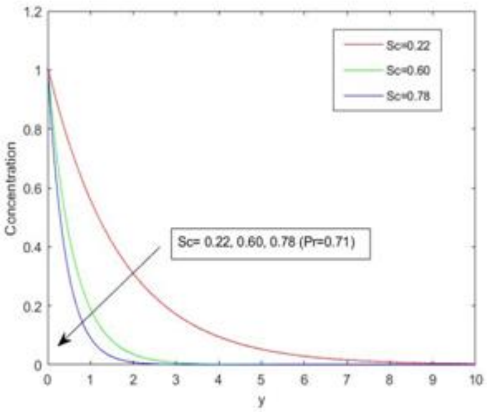

Figure 20. Sc on CP (Gr=5)

Figure 2 to Figure 5 imply the effect of M and Sc on the velocity profile (VP) of fluid for Pr = 0.71 and Pr = 7. They show velocity drops with the increase in the values of M and Sc. The application of magnetic field repels fluid transportation; hence velocity diminishes if M boosts up. The effect of K and Gm for Pr = 0.71 and Pr = 7 for fluid VP are depicted in Figure 6 to Figure 9. The figures expose that velocity rises with the boom in the values of K and Gm. Figure 10 exhibits VP falls with rise in Df for cooled plate and reverse effect is produced in Figure 11 for heated plate. The influence of Pr, F and Q on temperature profiles (TP) are depicted in Figure 12 to Figure 17 for cooled and heated plates. The figures show temperature lowers with enlargement in the values of Pr, F and Q. As Pr increases, thermal boundary layer thickness reduces, hence temperature falls for the rise in value of Pr. Figure 18 to Figure 21 exhibit the consequence of K_0 and Sc on concentration profile (CP) for Gr > 0 and Gr < 0. They exhibit that with the boost in K_0 and Sc, concentration reduces. The molecular diffusivity decreases as Sc value rises; hence concentration diminishes for enlarged Sc values.

The influences of Gm, M, K, Df, F and Q on SF and heat transfer rate (Nu) are validated in Table 1 and Table 2.

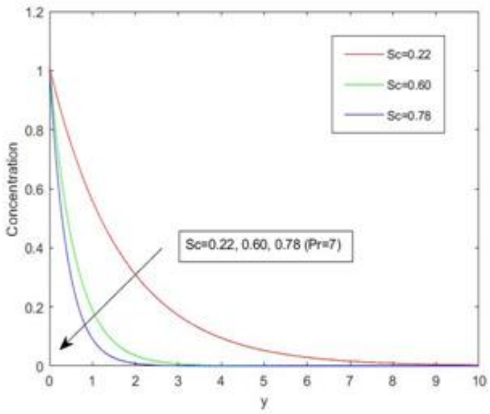

Figure 21. Sc on CP (Gr=-5.0)

Table 1. Variations in SF

Gm	M	K	SF τ (Gr = 5)				SF τ (Gr = - 5)			
			Pr =0.025	Pr =1.0	Pr =0.71	Pr =7	Pr =0.025	Pr =1.0	Pr =0.71	Pr =7
			Mercury	Electrolytic solution	Air		Mercury	Electrolytic solution	Air	
5			4.4980	5.3031	4.6095	2.2723	0.8460	1.5427	1.3879	3.4911
10			7.1590	8.7363	7.5563	4.3470	3.5289	4.9555	4.4387	7.1799
15			9.8128	12.1762	10.4683	5.8836	6.2191	8.3614	7.5241	11.4067
	2		4.4980	5.3031	4.6095	2.2723	0.8460	1.5427	1.3879	3.4911
	3		4.0170	4.0141	3.9215	2.0905	0.6813	1.2995	1.1113	2.9204
	4		3.6710	3.5210	3.5296	1.9556	0.5728	1.0814	0.9273	2.5431
		2	4.8239	8.9072	5.4406	2.3724	0.9682	0.9233	1.6265	4.0231
		3	4.9517	14.0595	5.9566	2.4077	1.0181	-1.2855	1.7031	4.2552
		4	5.0201	20.8213	6.3144	2.4256	1.0453	-5.0997	1.7291	4.3854

Table 2. Variations in Nusselt number

Df	F	Q	Nusselt Number Nu (Gr = 5)				Nusselt Number Nu (Gr = - 5)			
			Pr =0.025	Pr =1.0	Pr =0.71	Pr = 7	Pr =0.025	Pr =1.0	Pr =0.71	Pr = 7
			Mercury	Electrolytic solution	Air		Mercury	Electrolytic solution	Air	
1			1.4132	-2.3975	0.5092	10.5812	1.4326	0.9311	1.8053	10.4532
2			1.4176	-2.9224	0.5160	13.0101	1.4370	0.7803	1.9179	13.5243
3			1.4219	-3.4945	0.5193	15.4989	1.4415	0.5824	2.0269	16.6552
	4		0.7042	3.2930	2.3439	11.9028	1.0163	-0.5952	-0.0813	11.6852
	6		2.6576	3.5268	3.1926	11.5652	2.6011	2.9513	3.0521	11.1549
		3	1.9356	1.0954	-16.1709	12.1600	1.9925	-3.5705	-24.3061	12.1009
		5	2.3685	3.1634	3.2622	11.7106	2.2567	3.3657	0.4935	11.3809
		6	2.6576	3.5268	3.1926	11.5652	2.6011	2.9513	3.0521	11.1549

6. CONCLUSION

In this paper, discussions on mixed MHD convection flow of HAMT through an infinite plate that is vertical and porous with effects of Ohmic heating and viscosity dissipation have been explained in the existence of the Dufour effect, absorption and radiation, heat source or sink, and chemical reactions. The governing equations are modified into dimensionless form and then are explained by the method perturbation technique. The outcomes are represented in a graphical manner for various range of values of the parameters. The current analysis can be summarized as mentioned below:

i. Application of magnetic field transversely will reduce velocity of the fluid, in the flow hence velocity decreases with magnifying M for both cooled and heated plate.
ii. The enlargement in the value of Sc, will enlarge the viscosity of the fluid hence it retards the VP of the fluid for both Gr > 0 and Gr < 0.
iii. VP accelerates due to the raise of K and Gm for heated and cooled plate.
iv. The development in the value of Df lowers VP in cooled plate but reverse effect is produced in heated plate as rise in thermal energy flux increases VP.
v. TP crops as Pr increases because thermal boundary layer thickness decreases with rise in Pr value for both heated and cooled plates.
vi. Temperature diminishes with development in the values of F and Q; as the fluid releases energy to the surrounding in the form of heat due to radiation, which results in the lowering of temperature of fluid for plates in air and water.
vii. CP drops with accelerating values of K0 for both Gr > 0 and Gr < 0.
viii. Enlargement in the value of Sc means lowering of molecular diffusivity, which leads to reduction of boundary layer of concentration. Hence CP decreases for increase in the value of Sc for heated and cooled plate.
ix. The values of skin friction coefficient declines with increment in values of magnetic field parameter (M) for both cooled and heated plate in (i) mercury, (ii) electrolytic solution, (iii) air and (iv) water. The coefficient of skin friction increases with the rising values of mass Grashof number (Gm), permeability parameter (K) for both Gr < 0 and Gr > 0 for air, water, mercury and electrolytic solution.
x. The rate of heat transfer rises with the boosting of Df in cooled and heated plate except for electrolyic solution in heated plate.
xi. Nu expands with development in F for Gr > 0 and Gr < 0 excluding water in cooled plate.
xii. The rise in value of Q results in boom of Nu for cooled and heated plate omitting water in both plates.

7. APPLICATION

The results of the present study can be applied effectively to the development of many chemical engineering processes, including aeration, material vaporisation and condensation, crystal evolution and sublimation.

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NOMENCLATURE

B_0	Magnetic field strength
C_p	Specific heat at constant pressure
D	Chemical molecular diffusivity
D_{Kt}	Dufour coefficient
F	Radiation parameter
Gm	Mass Grashof number
Gr	Grashof number
K	Chemical reaction parameter
K_0	Chemical reaction rate constant
M	Magnetic parameter
Df	Dufour number
Nu	local Nusselt number along the heat source
Pr	Prandtl number
Q	Heat sink
Sc	Schmidt number

Greek symbols

β	thermal expansion coefficient
β^*	Solute expansion coefficient
θ	Dimensionless fluid temperature
φ	Dimensionless species concentration of the fluid
ρ	Fluid density
σ	Electrical conductivity
μ	dynamic viscosity

Subscripts

T_w	Temperature at the stationary plate
T_∞	Temperature of the free flowing fluid
C_w	Concentration at the stationary plate
C_∞	Concentration of the free flowing fluid