Heat and mass transfer effect between vertical plates through porous medium and chemical reaction effect on free convective MHD flow with soret effect

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Abstract. This Problem deals with an oscillatory progression of an electrically conducting liquid with viscosity in the two dimensional field. MHD, mass and heat transfer are all consider here. The fluid passes through a permeable moving wet porous plate in the presences of transverse magnetic field. Vertical infinite porous plate is considered here.. Thermal diffusion effect is added into the governing equation. By using the perturbation technique, the analytical solution of the problem was obtained for the velocity, temperature and concentration profiles, Various non-dimensional parameters like Soret number, Schmidt number, Modified Grashof number, Prandtl number for heat and mass transfer are all discussed and he results depicted through graphs.

1. Introduction
The process of stream and heat process together occurs simultaneously in a moving fluid. The idea of concurrent heat and mass exchange is utilized in different science and engineering issues. Free convective stream in nearness of warmth source has been a subject of enthusiasm of numerous specialists on account of its conceivable application to geophysical sciences, astrophysical sciences, and in amusing examinations. Such streams emerge either because of temperamental movement of the limit or the limit temperature. The study of shifting flow is important in the paper industry and many other industrial fields.. The possibility of simultaneous heat and mass trade is used in various science and designing issues industry and numerous other innovative fields. It is reasonable to examine the sunlight based structures and planetary, interstellar issue, radio spread through the ionosphere and so forth. In designing in MHD siphons, MHD orientation and so forth at high temperatures accomplished in some building gadgets, gas and so forth. Warm dispersion or soret impact in the permeable medium is a functioning exploration subject because of its wide application practically speaking. Due to the trouble in estimating warm dissemination and mass dispersion coefficients precisely, It is trusted that numerical models could give dependable outcomes and hence lessens the weight of expensive
examinations. Temperature inclination filter additionally be utilized to instigate movement of colloidal particles. This wonder, known as the Ludwig-Soret impact is regularly alluded to as thermophoresis. It has been known for around multi year. Miniaturized scale particles that are fueled by temperature inclinations have been tentatively illustrated.

Gupta et al [1] have discussed the Heat Transfer and MHD Flow of Convective Effects which lies between Vertical Plates Moving in Opposite Direction and Partially Filled with a Porous Medium. Chaudhary and P. Jain [2] Sahoo et al [3], R. Kumar and Chand [4], Chamkha [5] ,Gupta and Sharma [6] are discussed about these related topics. Krishna D.V et al [7] examined Hydro magnetic convection flow through a porous medium in a rotating channel. Vidhya et al [8], Govindarajan et al [9-11], Niranjana et al [12] are investigated about these correlated topics, Panda et al [13] studied about unsteady free convection flow and mass transfer past a vertical porous plate. Mohammad Al Zubii [14] is discussed about the related concepts of soret effect through porous medium with chemical reaction.

The basic idea of this paper is to examination about the MHD oscillatory progression of an electrically conducting liquid goes through a vertical, unending immersed permeable medium with soret impact within the sight of cross over attractive field. The permeable plate is in moving condition.

2. Mathematical Analysis

We consider a laminar non Darcian, two dimensional unsteady mixed convectional flow of an incompressible, viscid, specific conductance fluid over an infinite perpendicular porous plate made with thoroughly wet porous medium. By avoiding the persuaded magnetic field, we apply the magnetic strength (B0) perpendicular to the surface, y’ axis is considered normal to the surface whereas x’ axis is taken vertical direction along the planar surface. On the basses of the consideration of the immeasurable plane surface, the fluid flow variables are the functions of y’ and the time t’ only. At the beginning stage, the plate and the fluid are at relaxation mode, then as time increases, the total system is moving with a fixed velocity. The temperature of the plate is expanded unexpectedly to Tw at t = 0 and kept up steady after that.

The Principal equations are as follows,

\[ \frac{\partial \nu^*}{\partial t^*} + v^* \frac{\partial \nu^*}{\partial y^*} = v \frac{\partial^2 \nu^*}{\partial y^2} + \nu_T \frac{\partial^2 \nu^*}{\partial y^2} + g \beta_T (T^* - T_w^*) + g \beta_C (C^* - C_{\infty}^*) - \frac{\sigma B_0^2}{\rho} u^* - \frac{v}{K} u^* - \frac{v}{K} u^* \]  

\[ \frac{\partial T^*}{\partial t^*} + v^* \frac{\partial T^*}{\partial y^*} = \frac{\partial^2 T^*}{\partial y^2} \]  

\[ \frac{\partial C^*}{\partial t^*} + v^* \frac{\partial C^*}{\partial y^*} = D^* \frac{\partial^2 C^*}{\partial y^2} + \gamma_T (C^* - C_{\infty}^*) + \frac{m}{\rho} \frac{\partial^2 T^*}{\partial y^2} \]  

Here \( u^* \), \( v^* \) are the velocity components at any point \( (x^*, y^*) \). Where \( C^* \) is the species mass concentration and \( T^* \) temperature profile in the fluid flow. Then \( \nu^* \) - kinematic viscosity, \( \nu_T^* \) - kinematicrotationalviscosity, \( \rho \) - fluid density, \( \sigma \) – electrical conductivity of the fluid, \( \beta_T^* \) - volumetric thermal expansioncoefficient, \( \beta_C^* \) -mass volumetric expansion, \( g \) –gravitational acceleration, \( T_m^* \) Mean fluid temperature, \( D^* \) - diffusion coefficient, \( K^* \) - permeability of the porous medium, \( \gamma_T \) – spin gradient viscosity, \( \gamma \) -mass of the micro inertia per unit, \( \gamma_T \) - chemicalreactionparameter,\( D_m \) – coefficient of mass diffusivity, \( K_T \) - thermal diffusin ratio.

The applicable boundary condition n for the problem is given by,

\[ u^* = u_p^* \cdot T^* = T_w^* + \varepsilon (T_w^* - T_{\infty}^*)e^{nt^*}, C^* = C_{\infty}^* + \varepsilon (C_{\infty}^* - C_{\infty}^*)e^{nt^*} \text{at } y^* = 0, \]

\[ u^* \rightarrow 0, T^* \rightarrow T_{\infty}^*, C^* \rightarrow C_{\infty}^*, \text{ asy}^* \rightarrow \infty, \]

On integrating the equation (1),we get

\[ v^* = -V_0 \]  

Where, \( T_{\infty}^* \) is the temperature and \( C_{\infty}^* \) is the mass concentration at the free stream,V_0 is the scale of the suction velocity.

We use such non dimensional variables as given below,
\[ u = \frac{u^*}{u_0}, \quad t = \frac{v_0^2}{v} t^*, \quad \theta = \frac{T^* - T_\infty}{T_\infty - T_\infty}, \quad \phi = \frac{c_\infty - c_\infty^*}{c_\infty - c_\infty^*}, \]
\[ v = \frac{v^*}{v_0^2}, \quad G_r = \frac{\nu \beta (T_\infty - T_\infty^*)}{u_0 v_0^2}, \quad G_m = \frac{\nu \beta c (C_\infty - c_\infty^*)}{u_0 v_0^2}, \quad \gamma = \frac{\nu^2}{v_0^2}, \quad S_r = \frac{\nu D_{mR} (T_\infty - T_\infty^*)}{\gamma (c_\infty - c_\infty^*)}, \]
\[ y = \frac{v_0}{v} y^*, \quad M = \frac{\rho_0 v}{\rho v_0^2}, \quad \beta = \frac{v^*}{v}, \quad \lambda = \frac{K v_0^2}{v^2}, \quad n^* = \frac{v_0^2}{v} n, \quad \eta = \frac{u_0}{U}, \quad P_r = \frac{v}{\alpha}, \quad S_c = \frac{v}{D}, \]

where \( \beta \) denotes dimensionless viscosity, \( \lambda \) – permeability parameter, \( U_0 \) is the free stream velocity, \( U_0 \) – is the dimensionless plate velocity, \( M \) – magnetic field parameter, \( G_m \) – Grashof number for heat transfer, \( \gamma_1 \) – dimensionless chemical reaction parameter, \( G_m \) – Grashof number for mass transfer, \( P_r \) – prandtl number, \( S_c \) – Schmidt number respectively.

The above equations (1) – (6) can be reduced with the support of equation (5) and we obtain the following result,

\[ \frac{\partial u}{\partial t} + (1 + \beta) \frac{\partial^2 u}{\partial y^2} + G_r \theta + G_m \phi - \frac{1}{\lambda} u - Mu = \frac{\partial^2 \theta}{\partial y^2} + \frac{1}{\lambda} \frac{\partial^2 \phi}{\partial y^2} + \gamma_1 \phi + S_c S_r \theta \]

Equation (8) holds for \( u \), \( \theta \) and \( \phi \). By applying the equation (12) in equation (8) – (10), and then equating the harmonic and non-harmonic terms, also omitting the coefficients of \( O(\varepsilon^2) \), then we obtain the equations as follows

\[ A_2 u_0'' + u_0' - A_3 u_1 = -G_m \theta_0 - G_m \phi_0 \]
\[ A_2 u_1'' + u_1' - A_4 u_1 = -G_r \theta_0 - G_m \phi_1 \]
\[ \theta_0'' + P_r \theta_0' = 0 \]
\[ \phi_0'' + S_c \phi_0' + \gamma S_r \phi_0 = -S_c^2 S_r \theta_0'' \]
\[ \phi_1'' + S_c \phi_1' + A_1 \phi_0 = -S_c^2 S_r \theta_1'' \]

With the following boundary conditions

\[ u_0 = U_p, \quad \theta_0 = \theta e^{nt}, \phi = \phi e^{nt} \text{ at } y = 0 \]

\[ u \to 0, \theta \to 0, \phi \to 0 \text{ as } y \to \infty \]

3. Solution of the problem

We may use the following linear transformations, along with boundary conditions in equation (11) to solve the equations from (8)-(10)

\[ h(y, t) = h_0(y) + \varepsilon h_1(y)e^{nt} + O(\varepsilon^2) \]

where \( h \) stands for \( u \), \( \theta \) and \( \phi \). By applying the equation (12) in equation (8) – (10), and then equating the harmonic and non-harmonic terms, also omitting the coefficients of \( O(\varepsilon^2) \), then we obtain the equations as follows

\[ A_2 u_0'' + u_0' - A_3 u_1 = -G_m \theta_0 - G_m \phi_0 \]
\[ A_2 u_1'' + u_1' - A_4 u_1 = -G_r \theta_0 - G_m \phi_1 \]
\[ \theta_0'' + P_r \theta_0' = 0 \]
\[ \phi_0'' + S_c \phi_0' + \gamma S_r \phi_0 = -S_c^2 S_r \theta_0'' \]
\[ \phi_1'' + S_c \phi_1' + A_1 \phi_0 = -S_c^2 S_r \theta_1'' \]

With the following boundary conditions

\[ u_0 = U_p, \quad u_1 = 0, \quad \theta_0 = 1, \quad \phi_0 = 1, \quad \phi_1 = 1 \text{ at } y = 0 \]

\[ u_0 = 0, \quad u_1 = 0, \quad \theta_0 = 0, \quad \phi_0 = 0, \quad \phi_1 = 0 \text{ as } y \to \infty \]

The solution of the equation (13) –(18) based on the boundary conditions in equation(19)areas follows

\[ \theta_0 = e^{r_1 y} \]
\[ \phi_0 = e^{r_1 y} + X_1 e^{r_2 y} \]

The final solution is obtained by

\[ u = (L_1 e^{r_1 y} + X_6 e^{r_2 y} + X_4 e^{r_3 y}) + \varepsilon(L_2 e^{r_{12} y} + X_{10} e^{r_4 y} + X_8 e^{r_5 y})e^{nt} \]

\[ \theta = e^{r_2 y} + \varepsilon(e^{r_3 y} e^{nt}) \]

\[ \phi = (e^{r_3 y} + X_1 e^{r_2 y}) + \varepsilon(e^{r_4 y} + X_2 e^{r_3 y})e^{nt} \]

Where, \( A_1 = \gamma_1 S_c - n S_c, A_2 = 1 + A_3 = M + \frac{A_2}{\lambda}, A_4 = n + A_3 \)
The coefficient of skin friction is given by

\[
\tau_2 = - Pr\frac{r_2}{2} - \frac{Pr^2 + 4nPr}{2}, \quad \tau_6 = - \frac{Sc^2}{2} - 4\gamma \frac{Sc}{2}, \quad \tau_8 = - \frac{Sc^2}{2} - 4A_4,
\]

\[
r_{10} = \frac{1 - \sqrt{1 + 4A_2 A_3}}{2A_2}, \quad r_{12} = \frac{1 - \sqrt{1 + 4A_2 A_4}}{2A_2},
\]

\[
X_1 = \frac{-Sc^2 S_2 r_2^2}{r_2^2 + S_2 r_2 + \gamma S_c}, \quad X_2 = \frac{-Sc^2 S_4 r_4^2}{r_4^2 + S_4 r_4 + A_1}, \quad X_3 = \frac{-Gr}{r_2^2 + r_2 + A_3}, \quad X_4 = \frac{-Gm}{r_6^2 + r_6 + A_3}, \quad X_5 = \frac{-GmX_1}{A_2 r_2^2 + r_2 + A_3},
\]

\[
X_6 = X_3 + X_5, \quad X_7 = \frac{-Gr}{A_2 r_4^2 + r_4 + A_4}, \quad X_8 = \frac{-GmX_2}{A_2 r_4^2 + r_4 + A_4}, \quad X_9 = \frac{-GmX_1}{A_2 r_2^2 + r_2 + A_3}.
\]

\[
L_1 = U_p - X_4 - X_6, \quad L_2 = (X_8 + X_10).
\]

The coefficient of skin friction is given by

\[
\left(\frac{\partial u}{\partial y}\right)_{y=0} = (L_1 r_{10} + X_6 r_2 + X_4 r_6) + \varepsilon (L_2 r_{12} + X_10 r_4 + X_8 r_8)e^{nt}
\]  (29)

The Nusselt number is given by

\[
\left(\frac{\partial \theta}{\partial y}\right)_{y=0} = r_2 + \varepsilon (r_4)e^{nt}
\]  (30)

The rate of mass transfer is given by

\[
\left(\frac{\partial \phi}{\partial y}\right)_{y=0} = (r_6 + X_1 r_2) + \varepsilon (r_8 + X_2 r_4)e^{nt}
\]  (31)

4. Results and discussions

The results are attained numerically and graphically for the various non-dimensional parameters included in this problem. The figures 1(a)-1(h) explains about the velocity profile, fig2(a)-temperature profile and fig3(a)-3(d) explains about the concentration profile of this problem.

![Figure 1(a), Velocity profile for Gm](image-url)

Pr= 0.5; Sc= 2; Sr= 2; gamal = 1; n = 0.5; t =1; M = 2; beta = 0.3; lamda = 5; Up= 0.01; Gr= 2;
Figure 1(b), Velocity profile for Gr

\[ \text{Pr}=1; \ \text{gamal}=1; \ n=0.5; \ t=1; \ M=2; \ \text{beta}=0.3; \ \text{Sr}=2; \ \text{lamda}=5; \ \text{Up}=0.01; \ \text{Gm}=1; \ \text{Sc}=2; \]

Figure 1(c), Velocity profile for M

\[ \text{Pr}=1; \ \text{Sc}=2; \ \text{Sr}=2; \ \text{gamal}=1; \ n=0.5; \ t=1; \ \text{beta}=0.3; \ \text{lamda}=5; \ \text{Up}=0.01; \ \text{Gr}=1; \ \text{Gm}=1; \]

Figure 1(d), Unsteady velocity profile

\[ \text{Pr}=1; \ \text{Sc}=2; \ \text{Sr}=2; \ \text{gamal}=1; \ n=0.5; \ M=2; \ \text{beta}=0.3; \ \text{lamda}=5; \ \text{Up}=0.01; \ \text{Gr}=1; \ \text{Gm}=1; \]

Figure 1(e), Velocity profile for Sr

\[ \text{Pr}=0.5; \ \text{Sc}=2; \ \text{gamal}=1; \ n=0.5; \ t=1; \ M=2; \ \text{beta}=0.3; \ \text{lamda}=5; \ \text{Up}=0.01; \ \text{Gr}=1; \ \text{Gm}=1; \]
Figure 1(f), Velocity profile for $\text{Sc}$ 

$\text{Pr}=1; \text{Sr}=1; \text{gamma}=1; n=0.5; t=1; M=2; \beta=0.3; 
\lambda=5; U_p=0.01; \text{Gr}=1; \text{Gm}=1$;  

Figure 1(g), Velocity profile for $\lambda$ 

$\text{Pr}=0.5; \text{Sc}=1; \text{Sr}=2; \text{gamma}=1; n=0.5; t=1; M=2; \beta=1; 
U_p=0.01; \text{Gr}=1; \text{Gm}=1$; 

Figure 1(h), Velocity profile for $\text{Pr}$ 

$\text{Sc}=2; \text{Sr}=1; \text{gamma}=1; n=1; t=1; M=2; \beta=2; 
\lambda=0.5; U_p=0.01; \text{Gr}=1; \text{Gm}=2$; 

Figure 2(a), Temperature profile for $\text{Pr}$, 

$n = 0.1; t = 1$;
Figure 3(a), concentration profile for Sr
Pr= 0.2; Sc=1; gamal=0.01; n=0.1; t=0.01;

Figure 3(b), concentration profile for Sc
Pr= 0.1; Sr = 0.5; gamal = 0.01; n = 0.1; t =0.01;

Figure 3(c), Concentration profile for Pr
Sc=0.5; Sr=0.5; gamal=0.01; n=0.1; t=0.1;

Figure 3(d), Concentration Profile for $\gamma_l$
Pr=0.2; Sc=0.5; Sr=0.5; n=0.1; t=1;

Figure 1(a) indicates that the velocity profile for the various values of modified Grashof number for mass transfer. It is evident that, if the Grashof number Gm increases, there is an increase in the value of velocity profile. Figure 1(b) discus about the velocity profile for different values of $G_r$. The velocity profile rises due to an increase in the thermal Grashof number on the basis of enrichment in the buoyancy force. Figure 1 (c) illustrate about the velocity profile for different values of Magnetic Number M. Due to the applications of Lorenz force, the velocity profile decreases with an increase in the magnetic field parameter. Figure 1(d) shows the unsteady velocity profile, there is an increase in the velocity profile along with the time increases. Figure 1(e) and 1(f) explain about the velocity for various values Soret number $S_r$ and the Schmidt number $S_c$. In both the cases, the velocity profile increases with an increase in the value of $S_r$ and $S_c$. Figure 1(g), indicates the velocity distribution for the permeability parameter $\lambda$, the effect of velocity profile increases with an increase in the
permeability parameter this is for the explanation that the permeable medium in the liquid stream gives the opposition in the stream. Along these lines, the final resistive power will in general moderate the movement of the fluid. In Figure 1(h), we can visualize that the effect of Prandtl number $P_r$ for different values of velocity profile. The largest value of Prandtl number maintains to quicker cooling of the plate. The Prandtl number increases with the decreasing case of velocity profile. Figure 2(a) shows the temperature profile for various values of Prandtl number. It has the similar effect as shown in Figure 1(h), the temperature profile diminishes with an expanding instance of Prandtl number.

Figure 3(a) and 3(b) shows the concentration distribution for the various values of thermal diffusion coefficient parameter $S_r$ and the Schmidt number $S_c$. here, the concentration profile increases at the maximum level near the surfaces and then it decreases till it touches an asymptotic value. Figure 3(c) shows the concentration profile for different values of Prandtl number $P_r$. The fluid concentration decreases due an increase in Prandtl number. Figure 3(d) outline the impact of concentration profile for various estimations of chemical reaction parameter $\gamma_1$, concentration profile diminishes because of an expansion in the chemical reaction parameter.

5. Conclusion

The two dimensional, viscous fluid with an oscillatory flow, which is concern with electricity with heat and mass transfer effects over an endless perpendicular stirring absorbent plate which is placed in a saturated porous plate along with the crosswise magnetic field by having the Soret effect and chemical reaction. It is observed that, by increasing the Grashof number for heat transfer $G_r$, Grashof number for mass transfer $G_m$, Soret effect parameter $S_r$, Schmidt number $S_c$, permeability parameter $\lambda$ and the variation of time factor leads to an increase in the velocity profile. On the other hand, the velocity profile decreases due to an increase in the Magnetic field parameter $M$ and Prandtl number $P_r$. The temperature profile accomplishes its greatest level close to the surfaces and then reductions far away from the divider till it arrives at an uneven direct on account of Prandtl number. The concentration deceases as the chemical reaction parameter $\gamma_1$, Schmidt number $S_c$, thermal diffusion parameter $(S_r)$, Prandtl number $P_r$ and are all increases.

References

[1] Gupta V G, Ajay Jain and Abhay Kumar Jha (2016) Convective Effects on MHD Flow and Heat Transfer between Vertical Plates Moving in Opposite Direction and Partially Filled with a Porous Medium Journal of Applied Mathematics and Physics (4) 341–358
[2] Chaudhary R C and Jain P (2006) Hall effect on MHD mixed convection flow of a viscoelastic fluid past and infinite vertical plate with mass transfer and radiation Theoretical and Applied Mechanics 33(4) 281–309
[3] Sahoo S N, Panda J P and Dash G C (2011) Unsteady two dimensional MHD flow and heat transfer of an elastic-viscous liquid past an infinite hot vertical porous surface bounded by porous medium with source/sink A.M.S.E. France 80(2) 26–42
[4] Kumar R and Chand K (2011) Effect of slip conditions and Hall current on unsteady MHD flow of a viscoelastic fluid past an infinite vertical porous plate through porous medium International Journal of Engineering Science and Technology 3(4) 3124–3133
[5] Chamkha A J (2000) Thermal radiation and buoyancy effects on hydro magnetic flow over an accelerating permeable surface with heat source or sink Int. J. Heat Mass Transfer 38 1699–1712
[6] Gupta M and Sharma S (1991) MHD flow of viscous fluid through a porous medium bounded by an oscillating porous plate in slip flow regime ActaCienciaIndica 17M 389–394
[7] Krishna D V, PrasaadRao D R V and Ramachandra Murthy A S (2002) Hydromagnetic convection flow through a porous medium in a rotating channel J EngPhysThermophys 75(2) 281–291
[8] Vidhya M and SundarammalKesavan (2010) Proceedings of the International Conference on
Frontiers in Automobile and Mechanical Engineering (Scopus Indexed), IEEE Explorer, Available in online, 248–251

[9] Govindarajan A, Ramamurthy V and Sundarammal K (2007) Journal of Zhejiang University-SCIENCE A 8(2) 313–322

[10] ArunachalamGovindarajan, Ali J. Chamkha, SundarammalKesavan and MohanakrishnanVidhya (2014) Thermal Science 18(2) S515S526 (Web of Science).

[11] Govindarajan A, Rajesh K, Vidhya M and Siva E P (2019) AIP Conference Proceedings 2112 020184

[12] Niranjana N, Vidhya M, Govindarajan A, Siva E P and Priyadarshini E (2019) Effects of Thermal Diffusion and Mass Transfer on Oscillatory Flow through Porous Medium in the Presence of Magnetic Field with Heat Source AIP Conference Proceedings 2112 020110

[13] Panda J P, Dash G C and Dash S S (2003) unsteady free convection flow and mass transfer past a vertical porous plate AMSE Modelling B, 72(3) 47

[14] Mohammad Al Zubi (2018) MHD Heat and Mass transfer of an Oscillatory Flow over a Vertical Plate in a Porous Medium with chemical reaction Modern MechanicalEngineering 8 179–191.