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*Research Article*

# Changeable Heat and Mass Transport on Unsteady MHD Convective Flow Past an Infinite Vertical Porous Plate

**Borevella Chandra Sekhar** [a], **Prathi Vijaya Kumar** [a], **M. Veera Krishna** [b*]

[a] *Department of Mathematics, GITAM (Deemed to be university), Visakhapatnam, Andhra Pradesh, 530045, India.*

[b] *Department of Mathematics, Rayalaseema University, Kurnool, Andhra Pradesh, 518007, India.*

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**ABSTRACT**

It has been explored the unsteady MHD convection flows during loosely packed permeable media into a precipitately starting perpendicular plate by the changeable temperature as well as mass transportation. The temperature of the plate rises linearly over time. The fluid taken is as gray engrossing, or emitted and radiating but the non-scattering media. The governing equations of the current investigation are resolved by the Laplace transformation methodology. The velocity, temperature, as well as concentration, are found systematically and numerically explored for various governing parameters. Also, the skin friction, Nusselt number, and Sherwood numbers by the combinations of distinct flow parameters are demonstrated in graphical profiles, as well as physical features of the problem are explored. It is found that the magnitude of the velocity is increased by enhancement into the quantities of penetrability parameter. The magnitude of the velocity is enhanced as it trims down incessantly by increasing into the radiating parameter. The velocity increases over time. The magnitude of the velocity is decreased by an increase in the Prandtl number. The temperature is reduced by an increase in the radiating parameters and/or Prandtl numbers. The growing quantities of the Schmidt number led to the concentration profile complete liquid area. Nusselt number is growing by increasing into radiating parameter and Prandtl number.

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## 1. Introduction

The magnetohydrodynamic (MHD) is the subdivision of fluid dynamics. It explored the group of the electrically performing liquids with the magnetic fields. Numerous of investigation attempts in the MHD has been proceeding widely for the durations of the earlier some decades succeeding to the lot of researcher into the fluid metalizing channel/ducts flows under externally magnetic fields. There is the mainly applications for the parabolic flow, for illustration solar cookers, solar concentrators and parabolic through stellar collectors. The parabolic concentrator models solar cooker had the extensive range of applications, for example baking, roasts and distillations. Solar concentrator models have those applications into producing rate of evaporation to dissipating stream, in food dispensation, for produce consumption water from salty water and sea water.

Convection temperature transportation in absorbent media had been the theme of enormous attention for the proceeding only some decades. This attention has been motivating with

* **Corresponding author.**
***E-mail address:*** veerakrishna_maths@yahoo.com

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the plentiful thermal engineering systems into different regulations, they are, geo-physical, thermal and the insulation engineering, a model of crowd sphere bed, the freezing of the electronic systems, chemical catalytic reactor, ceramic processing, grained storages device fiber and granular insulation, petroleum reservoir, coal combustor, ground water pollution and filtration process.

Kim [1] explored an unsteady MHD convection temperature transportation over the semi-infinite perpendicular absorbent moving plate by the changeable suction. Afterwards Chamkha [2] expanded the works of Kim [1] into this he explored the unsteady MHD convective temperature and accumulation transportation past the semi-bounded less upright spongy affecting plate by the temperature absorption. Gokhale et al. [3] explored the consequences of mass transportation on the transitory liberated convection movement of the dissipation fluid over the half-unbounded perpendicular plate by the non-constant temperature flux. Alam et al. [4] conferred the geometrical revision of the mixed liberated and/or forced convection and mass transportation movement over the upright absorbent plate into the porous medium with the temperature generating and thermal diffusion. Hossain et al. [5] explored the consequences of the radiating of free convective movement of fluid by the changeable viscosity from the absorbent upright plate.

The MHD free convective movement occurred commonly into the nature. The submission of MHD incompressible gelatinous flow into science and engineering involving temperature transportation under the control of chemical reaction were of the huge significances into countless regions of science and engineering. These recurrently occurring in the petrochemical industry, power and cooling systems, chemical vapour deposition on the surface, glacial of the nuclear reactors, temperature exchanger design, forest fired dynamics and geo-physics and MHD power generating organizations. The effects of thermal conductivity on the temperature, and it is inversely proportional with the linear function of temperature on the liberated convective flow of the incompressible viscous fluids through the heated uniformed and perpendicular wavy surfaces had been examined by Krishna [6]. Sahinet al. [7] explored the united temperature and accumulation transports with mixed convection MHD movement alongside the leaky plate by the chemical reaction into the representing of temperature source. Chaudhaury et al. [8] explored mixed temperature and mass transports consequences on the MHD liberated central heating flow over an fluctuating plate entrenched in absorbent media. Ravikumar et al. [9] explored the MHD twofold diffusion and chemical reactive flow between a porous media delimited with two upright plates. Ravikumar et al. [10] discussed temperature and accumulation transport consequences on the MHD flow of glutinous fluid during non-homogeneous absorbent media into their presenting of temperature dependent heat source. The temperature and accumulation transport consequences on three dimensional MHD Couette flow past the leaky plate by the temperature dependent heating source have been explored by Ravikumar et al. [11]. Singh et al. [12] investigated the fluctuating temperature and accumulation transport on unsteady MHD normal convection flow of radiating and chemical reacting fluid over the perpendicular absorbent plate into slip-flow regime. Krishna et al. [13] discussed the chemical reacting, temperature absorption and Newtonian heating on the MHD complimentary convection Casson hybrid nanoliquid over an unbounded fluctuating perpendicular absorbent plate.

Rajesh et al. [14] explored the radiating temperature and accumulation transports on the MHD complimentary convective flow over an exponential increase speed perpendicular plate by the changeable temperature. Israel-Cookeyet al. [15] explored the influence of jellylike dissipation on the unsteady MHD liberated convection flow past an unlimited impassioned vertical plate into absorbent media by the time dependent suction. Raju et al.[16] explored the unsteady MHD liberated central heating fluctuating Couette flow through the absorbent media by the periodic wall temperature.

Daleepet al. [17] investigated the bounds for complexity growing pace in thermal and solutal central heating into Rivlin–Ericksen visco-elastic hydrodynamic fluid into the spongy media. Noushima et al. [18] explored the MHD free convection Rivlin–Ericksen flows during the absorbent media by the changeable penetrability. Rana [19] investigated thermal unsteady of gaseous Rivlin-Efficksen gyrating liquid permeated by the overhanging dusted particles into absorbent media. Sharma et al. [20] explored the Hall impacts onto the thermal unsteady of Rivlin–Ericksen fluids during the planar channel. Gupta et al. [21] conferred onto the Rivlin–Ericksons elastico-viscous liquid heat and resolution into the representing of compressibility, revolution and Hall consequences. Uwanta et al. [22] discussed the consequences of mass transfers onto the MHD free convective Rivlin–Ericksen fluid flows during the absorbent media by the time reliant suction. Varshney et al. [23] explored the consequences of gyratory Rivlin–Ericksens fluids on the MHD liberated convection and accumulation transfers flow during absorbent media by the invariable temperature and accumulation efflux over moving plate. The magnetic field consequences on the transient liberated convective flows during an absorbent media over a spontaneously happening perpendicular plate by the oscillating temperatures as well as accumulation diffusions have been explored by Ravikumar et al. [24]. Krishna et al. [25] explored the temperature and accumulation transport on the MHD flow over an unlimited the non-conducting perpendicular flat porous plate. Babu [26] discussed the numerical investigation of Newtonian heating consequences on the unsteady MHD liberated convective movement of radiation and chemical reactive Cassons fluids past an unlimited fluctuations vertical plate entrenched into a porous medium by the temperature sink and glutinous dissipations. The numerical model of the activation energy and MHD non-Newtonian fluids particles deposition flow into the rotating disks have been discovered by Babu et al. [27]. Babu et al. [28] investigated the model of Cattaneo-christov temperature and accumulation transports efflux on non-Newtonian MHD fluid by the changeable thermal and solutal properties. The physical concepts and streamline analysis on MHD non-linear radiation flows of Carreau-Yasudas fluids through planar channels have been discussed by Babu et al. [29].

Goud [30] discussed the heat generation/absorption influence on steady stretched permeable surface on MHD flow of a micropolar fluid through a porous medium in the presence of variable suction/injection. Goud and Nandeppanavar [31] explored the effect of thermal radiation on MHD heat transfer micropolar fluid flow over a vertical moving porous plate. The effects of inclined magnetic field on flow, heat and mass transfer of Williamson nanofluid over a stretching sheet has been explored by Srinivasulu and Goud [32]. Goud and Mahantesh [33] investigated the Ohmic heating and chemical reaction effect on MHD flow of micropolar fluid past a stretching surface. Goud et al. [34] explored the finite element method on the radiation, Soret, Dufour numbers effect on MHD Casson fluid over a vertical permeable plate in the presence of viscous dissipation. Amar et al. [35] discussed the MHD heat transfer flow over a moving wedge with convective boundary conditions with the influence of viscous dissipation and internal heat generation/absorption. Induced magnetic field effect on MHD free convection flow in nonconducting and conducting vertical microchannel walls has been explored by Goud et al. [36]. Hussain et al. [37] discussed the effectiveness of nonuniform heat generation and thermal characterization of a carreau fluid flowing across a nonlinear elongating cylinder. Hari Babu et al. [38] explored the non-linear radiation and dissipative impacts on non-Newtonian hydromagnetic Falkner-Skan fluid through a wedge. Hall and ion-slip effects on MHD free convection flow of rotating Jeffrey fluid over an infinite vertical porous surface have been discussed by Hari Babu et al. [39]. Hari Babu et al. [40] explored the numerical analysis of flow characteristics of Jeffery nanofluid past a moving plate in conducting field. Hari Babu et al. [41] explored the heat and mass transfer on Unsteady MHD convective flow of Casson hybrid nanofluid over a permeable media with ramped wall temperature. Raju et al. [42] investigated Hall effects on the MHD convective rotating flow of viscoelastic fluid past an infinite vertical oscillating porous plate. Raghunath et al. [43] explored Influence of MHD mixed convection flow for maxwell nanofluid through a vertical cone with porous material in the existence of variable heat conductivity and diffusion. Suresh Kumar et al. [44] discussed the numerical analysis of MHD Casson nanofluid flow with activation energy, Hall current and thermal radiation. Raghunath et al., [45] discussed the thermal radiation effects of 3D rotating hybrid nanofluid reactive flow via stretched plate with internal heat absorption. Unsteady magneto-hydro-dynamics flow of Jeffrey fluid through porous media with thermal radiation, Hall current and Soret effects has been explored by Raghunath et al. [46]. Raghunath and Ramana [47] explored the Hall, Soret, and rotational effects on unsteady MHD rotating flow of a second-grade fluid through a porous medium in the presence of chemical reaction and aligned magnetic field. Das et al. [48] explored the dynamics pattern of a radioactive rGO-magnetite-water flowed by a vibrated Riga plate sensor with ramped temperature and concentration. Ali et al. [49] discussed the MHD gyrating stream of non-Newtonian modified hybrid nanofluid past a vertical plate with ramped motion, Newtonian heating and Hall currents. Hall effects on unsteady MHD rotating flow past a periodically accelerated porous plate with slippage have been discussed by Das et al. [50]. Das et al. [51] explored the Hall effects on an unsteady magneto-convection and radiative heat transfer past a porous plate. Ali et al. [52] discussed the Hall and ion slip current's impact on magneto-sodium alginate hybrid nanoliquid past a moving vertical plate with ramped heating, velocity slip and Darcy effects. Hosseini et al. [55] explored the heat transfer analysis of nanofluid flow on elliptical tube bundle with different attack angles. Nemati et al. [56]discussed the cooling of two hot half-cylinders through MHD non-newtonian ferrofluid free convection under heat absorption; investigation of methods to improve thermal performance.

Motivated on the above studies, the unsteady MHD convection flows through a loosely packed permeable medium into a precipitately started perpendicular plate by the changeable temperature as well as mass transportation have not been explored yet. Therefore in the present investigations, it is explored the unsteady MHD convection flows through a loosely packed permeable medium into a precipitately started perpendicular plate by the changeable temperature in addition to mass transportation. The temperature of the plate is increased linearly by the timing. The liquid taken is as gray, absorbing and/or emitting radiating since the non-scattering media. The governing equations in the current investigation are solved by making utilization of the Laplace transformation methodology.

## 2. Formulation and Solutions of the Problem

We have supposed the flows of the tremulous MHD convection flows through a loosely packed permeable medium into a precipitately started perpendicular plate by the changeable temperature as well as mass transportation. The physical configuration of the problem is as shown in the Fig. 1. The following assumptions are made as,

1. The temperatures of plate make into rises linearly by the time.
2. The liquid taken is as gray, absorbing and/or emitting radiating but the non-scattering medium.
3. The x-direction is taken alongside the plate into the rising direction in addition to the y – direction is moving normal into the plate.
4. Primarily, the fluids as well as plate were near the identical temperatures.
5. The transverse magnetic fields B0 of uniformed strengthening is apply normal to a plate.
6. The viscous dissipations and induced magnetic field have been ignored owing to those little effects.
7. The fluids as well as the plate were near the identical temperaturesT1 in addition to concentrations C1 into the stationary conditions.
8. At some instant of the time t > 0, the plate was affecting by the velocity u = u0 into its own planes as well as the temperatures of the plate was raising to Tw as well as the concentrations levels at the plate was raising linearly with respected to the time.

The unsteady MHD convection flows during loosely packed permeable media into a precipitately starting perpendicular plate by the changeable temperature as well as mass transportation are as (Hossain et al. [5] and Krishna et al. [54]),

$$\frac{\partial u}{\partial t}=\nu\frac{\partial^2 u}{\partial y^2}-\frac{\sigma B_0^2}{\rho}u-\frac{\nu}{k}u+g\beta(T-T_\infty)+g\beta^*(C-C_\infty) \quad (1)$$

$$\rho C_p\frac{\partial T}{\partial t}=K\frac{\partial^2 T}{\partial y^2}-\frac{\partial q_r}{\partial y} \quad (2)$$

$$\frac{\partial C}{\partial t}=D_1\frac{\partial^2 C}{\partial y^2} \quad (3)$$

The primary as well as boundary conditions as (Hossain et al. [5] and Krishna et al. [54]),

$$u=0, T=T_\infty, C=C_\infty, \quad t\le 0, \ \forall\ y \quad (4)$$

$$u=u_0, T=T_\infty+(T_w-T_\infty)At, \quad C=C_\infty+(C_w-C_\infty)At, \quad \text{at } y=0 \quad (5)$$

$$u\to 0, T\to T_\infty, C\to C_\infty, \quad y\to\infty \quad (6)$$

where, $A=\frac{u_0^2}{\nu}$ .

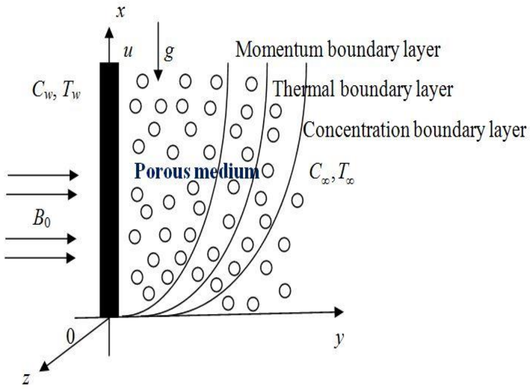


**Fig. 1.** Physical model

The local radiant for the casing of an optically thinner gray gas was explored by,

$$\frac{\partial q_r}{\partial y}=-4a^*\sigma(T_\infty^4-T^4) \quad (7)$$

Captivating the temperatures differences within the flows adequately smallest, $T^4$ might be articulated as the linearly functions of temperatures. It is consummate by intensifying $T^4$ into the Taylor series regarded $T_\infty$ as well as ignoring highest ordered expressions, therefore,

$$T^4\cong 4T_\infty^3T-3T_\infty^4 \quad (8)$$

Using equations (7) and (8), equation (2) reduces to,

$$\rho C_p \frac{\partial T}{\partial t} = k\frac{\partial^2 T}{\partial y^2} + 16a^*\sigma(T_\infty^3 - T^4) \tag{9}$$

We introduce the subsequent non-dimensionalised quantities as,

$$u^* = \frac{u}{u_0}, y^* = \frac{yu_0}{\nu}, \theta = \frac{T - T_\infty}{T_w - T_\infty}, C^* = \frac{C - C_\infty}{C_w - C_\infty}, \mu = \rho\nu, t^* = \frac{tu_0^2}{\nu}$$

Making utilization of the non-dimensionalised quantities, the equations (1), (2) as well as (9) leds to (reducing asterisks),

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} - \left(M^2 + \frac{1}{D}\right)u + Gr\,\theta + Gm\,C \tag{10}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{\Pr}\frac{\partial^2 \theta}{\partial y^2} - \frac{R}{\Pr}\theta \tag{11}$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} \tag{12}$$

The relevant boundary conditions are as,

$$u = 0, \theta = 0, C = 0, \quad t \le 0, \ \forall\ y \tag{13}$$

$$u = 1, \quad \theta = t, \quad C = t, \quad y = 0 \tag{14}$$

$$u \to 0, \quad \theta \to 0, \quad C \to 0, \quad as \quad y \to \infty \tag{15}$$

where, $R = \frac{16a^*\nu^2\sigma T_\infty^3}{ku_0^2}$ is the Radiation parameter, $M^2 = \frac{\sigma_e B_0^2 \nu}{\rho u_0^2}$ is the Hartmann number, $D = \frac{ku_0^2}{\nu^2}$ is the Darcy parameter, $Gr = \frac{g\beta\nu(T_w - T_\infty)}{u_0^3}$ is the thermal Grashof number, $Gm = \frac{g\beta^*\nu(C_w - C_\infty)}{u_0^3}$ the mass Grashof number, $\Pr = \frac{\mu C_p}{K}$ is Prandtl parameter and $Sc = \frac{\nu}{D_1}$ is the Schmidt number.

The non-dimensional leading equations (10) to (12), subjected to the boundary conditions (13) to (15), are resolved with the normal Laplace transformation technique. By helping of Schiff [53] growth has also been engaged. The resolutions obtained and are specified under. After taking the Laplace transformation, then the transforming equation (12), it is found as,

$$s\overline{C}(y,s) - C(y,0) = \frac{1}{Sc}\frac{d^2\overline{C}}{dy^2} \tag{16}$$

Utilising boundary conditions (13) to (15), it is found as

$$\frac{d^2\overline{C}}{dy^2} - s\,Sc\,\overline{C}(y,s) = 0 \tag{17}$$

The solution of the equation (16) is determined as,

$$\overline{C}(y,s) = Ae^{\sqrt{sSc}\,y} + Be^{-\sqrt{sSc}\,y} \tag{18}$$

Where, $A$ as well as $B$ were arbitrary constants. Later, utilizing the above boundary conditions (13) as well as (14), it was found as

$$\overline{C}(y,s) = \frac{1}{s^2}e^{-\sqrt{sSc}\,y} \tag{19}$$

Considering the inverse Laplace transformation for the equation (19), it is obtained as,

$$C(y,t) = t\left(1 + 2\left(\frac{y}{2\sqrt{t}}\right)^2 Sc\right)erfc\left(\left(\frac{y}{2\sqrt{t}}\right)\sqrt{Sc}\right) - \frac{2\left(\frac{y}{2\sqrt{t}}\right)\sqrt{Sc}}{\sqrt{\pi}}e^{-\left(\frac{y}{2\sqrt{t}}\right)^2 Sc} \tag{20}$$

Also transforming equation (11),

$$s\overline{\theta}(y,s) - \theta(y,0) = \frac{1}{\Pr}\frac{d^2\overline{\theta}}{dy^2} - \frac{R}{\Pr}\overline{\theta}(y,s) \tag{21}$$

Utilizing the frontier situations (13) as well as (14), this reduced to as,

$$\frac{d^2\overline{\theta}}{dy^2} - (R + s\Pr)\overline{\theta}(y,s) = 0 \tag{22}$$

The resolutions of the equation (21) are,

$$\overline{\theta}(y,s) = C\,e^{y\sqrt{R+s\Pr}} + E\,e^{-y\sqrt{R+s\Pr}} \tag{23}$$

Where $C$ and $E$ are arbitrary constants. The values of $C$ and $E$ might be determined utilizing (13) and (14), it is found as,

$$\overline{\theta}(y,s) = \frac{1}{s^2}e^{-y\sqrt{\Pr\left(s + \frac{R}{\Pr}\right)}} \tag{24}$$

Considering the inverse Laplace transformation for the equation (23) it is found as,

$$\theta(y,t) = \frac{t}{2}\left(a_1 e^{2\xi\sqrt{Rt}}erfc(\xi\sqrt{Pr} + \sqrt{ct}) + a_2 e^{-2\xi\sqrt{Rt}}erfc(\xi\sqrt{Pr} - \sqrt{ct})\right) \tag{25}$$

Likewise, another time captivating the Laplace transform to the equation (10) and making utilization of the initial and boundary conditions (13) to (15), this reduced to as,

$$\frac{d^2\overline{u}}{dy^2} - \left[s + \left(M^2 + \frac{1}{D}\right)\right]\overline{u}(y,s) = -GrL\{\theta(y,t)\} - GmL\{C(y,t)\} \tag{26}$$

The solutions of the equation (26) is specified as,

$$\bar{u}(y,s) = F\,e^{y\sqrt{s+\left(M^2+\frac{1}{D}\right)}} + G\,e^{-y\sqrt{s+\left(M^2+\frac{1}{D}\right)}} + \frac{Gr}{1-\Pr}\frac{e^{-y\sqrt{Pr}\sqrt{s+\frac{R}{Pr}}}}{s^2(s-a_3)} + \frac{Gm}{1-Sc}\frac{e^{-y\sqrt{sSc}}}{s^2(s-a_4)} \tag{27}$$

Utilizing the boundary conditions (13) and (14) for (26), it is found as,

$$\bar{u}(y,s) = \frac{1}{s}e^{-y\sqrt{s+\left(M^2+\frac{1}{D}\right)}} + \frac{Gr}{1-\Pr}\left(\frac{e^{-y\sqrt{Pr}\sqrt{s+\frac{R}{Pr}}} - e^{-y\sqrt{s+\left(M^2+\frac{1}{D}\right)}}}{s^2(s-a_3)}\right) + \frac{Gm}{1-Sc}\left(\frac{e^{-y\sqrt{sSc}} - e^{-y\sqrt{s+\left(M^2+\frac{1}{D}\right)}}}{s^2(s-a_4)}\right) \tag{28}$$

Captivating the inverse Laplace transformation to the equation (28), it s obtaining the velocity as,

$$\begin{aligned}
u(y,t) &= a_5\, e^{-y\sqrt{\left(M^2+\frac{1}{D}\right)}}\, erfc\left(\xi - \sqrt{\left(M^2+\frac{1}{D}\right)t}\right) \\
&\quad a_6\, e^{y\sqrt{\left(M^2+\frac{1}{D}\right)}}\, erfc\left(\xi + \sqrt{\left(M^2+\frac{1}{D}\right)t}\right) + \\
&\quad -\Big[e^{-y\sqrt{\Pr(a_3+(R/\Pr))}}\, erfc(\xi\sqrt{\Pr} - \sqrt{(a_3+(R/\Pr))t}) + \\
&\quad e^{y\sqrt{\Pr(a_3+(R/\Pr))}}\, erfc(\xi\sqrt{\Pr} + \sqrt{(a_3+(R/\Pr))t})\Big]\frac{a_{11}}{2}e^{a_3 t} \\
&\quad -\left(a_7 e^{-y\sqrt{\Pr(R/\Pr)}}\, erfc(\xi\sqrt{\Pr} - \sqrt{(R/\Pr)t})\right. \\
&\quad \left.+a_8 e^{y\sqrt{\Pr(R/\Pr)}}\, erfc(\xi\sqrt{\Pr} + \sqrt{(R/\Pr)t})\right) \\
&\quad -\left[e^{-y\sqrt{\Pr\left(M^2+\frac{1}{D}+a_3\right)}}\, erfc\left(\xi\sqrt{\Pr} - \sqrt{\Pr\left(M^2+\frac{1}{D}+a_3\right)t}\right)\right. \\
&\quad \left.+e^{y\sqrt{\Pr\left(M^2+\frac{1}{D}+a_3\right)}}\, erfc\left(\xi\sqrt{\Pr} + \sqrt{\Pr\left(M^2+\frac{1}{D}+a_3\right)t}\right)\right]\frac{a_{11}}{2}e^{a_3 t} \\
&\quad +\left[e^{-y\sqrt{a_4 Sc}}\, erfc(\xi\sqrt{Sc} - \sqrt{a_4 t}) + e^{y\sqrt{a_4 Sc}}\, erfc(\xi\sqrt{Sc} + \sqrt{a_4 t})\right]\frac{a_{12}}{2}e^{a_4 t} \\
&\quad -\left[e^{-y\sqrt{\left(M^2+\frac{1}{D}+a_4\right)}}\, erfc\left(\xi - \sqrt{\left(M^2+\frac{1}{D}+a_4\right)t}\right)\right. \\
&\quad \left.+e^{y\sqrt{\left(M^2+\frac{1}{D}+a_4\right)}}\, erfc\left(\xi + \sqrt{\left(M^2+\frac{1}{D}+a_4\right)t}\right)\right]\frac{a_{12}}{2}e^{a_4 t} \\
&\quad -a_{12}\left[1 + a_4 t(1+2\xi^2 Sc)erfc(\xi\sqrt{Sc}) + \frac{2a_4 t\xi\sqrt{Sc}}{\sqrt{\pi}}e^{-\xi^2 Sc}\right]
\end{aligned} \tag{29}$$

The non-dimensional shear stress is given by,

$$\tau = -\left(\frac{du}{dy}\right)_{y=0} = -\frac{1}{2\sqrt{t}}\left(\frac{du}{d\xi}\right)_{\xi=0} \tag{30}$$

The non-dimensional Nusselt number is given by,

$$Nu = -\left(\frac{d\theta}{dy}\right)_{y=0} = -\frac{1}{2\sqrt{t}}\left(\frac{d\theta}{d\xi}\right)_{\xi=0} \tag{31}$$

The non-dimensional Sherwood number is given by,

$$Sh = -\left(\frac{dC}{dy}\right)_{y=0} = -\frac{1}{2\sqrt{t}}\left(\frac{dC}{d\xi}\right)_{\xi=0} \tag{32}$$

Where, all constants are mentioned in the Appendix.

## 3. Results and Discussion

We considered the flow of the unsteady MHD convection flow during a loosely packed permeable medium into a precipitately started perpendicular plate by the changeable temperature as well as mass transportation. The temperature of plate make into rises linearly by the time. The liquid taken is as gray, absorbing and/or emitting radiating but the non-scattering media. The appearance for the velocity, temperature and concentration are found by using Laplace transformation technique as well as discussed the physical features of the non-dimensional parameter they are Hartmann number M, Darcy parameter D (Penetrability parameter), radiation parameter R, thermal Grashof number Gr, mass Grashof number Gm, Prandtl number Pr and Schmidt number Sc. The Figures 2-12 have been explored for the velocity, temperature and concentration distribution. The skin friction, Nusselt number and Sherwood number are shown into the Tables 1-3. The velocity, temperature and concentration profiles for few practical quantities of Prandtl number Pr (Pr = 0.710, 0.160, 3.00 for the saturated fluid Freon at 273.3° and Pr = 7 for pure water) and Schmidt number Sc (Sc = 0.20 for H2) accordingly.

From the Figure 2, it is presenting the velocity profiles for dissimilar quantities of magnetic field parameter and other parameters being fixed. It is notified that the velocity is decreasing by an enhancing in the Hartmann number M. It is owing to the fact that the application of transverse magnetic field gives a resistive model force (Lorentzs force) similar to drag force and upon growing the intensity of the magnetic field this leads to the decelerating the flow field.

The Figure 3 is modelled in ordered to discover the disparities of penetrability parameter D. It is determined that, the magnitude of the velocity is increasing with an enhancing in the quantities of the permeability parameter D. It is owing to the fact that enhancing the penetrability retards the drag force these assist the fluid significantly to go quickly.

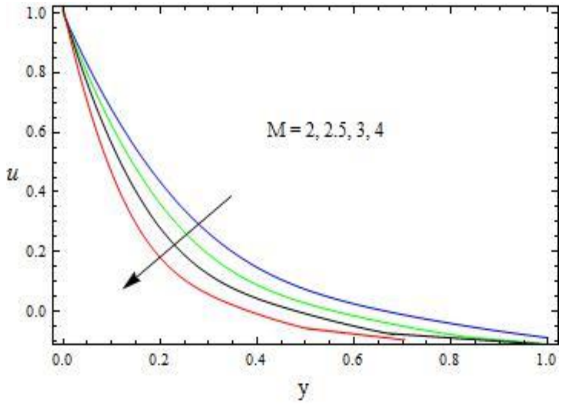


**Fig. 2.** The velocity Profile with *M*

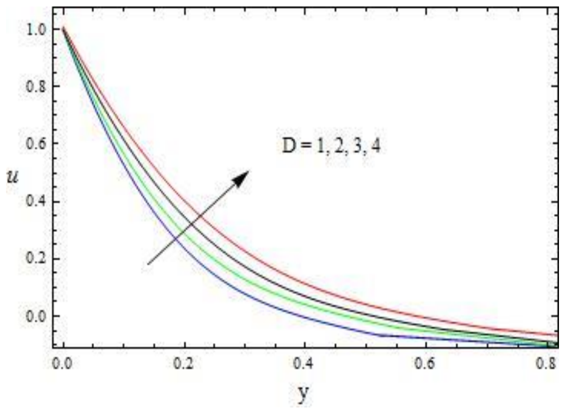


**Fig. 3.** The velocity Profile with *D*

Similarly, the magnitude of the velocity reduced incessantly by a growing in the radiating parameter R from the Fig. 4. The radiation parameter R defines the relative contribution of conduction heat transfer to thermal radiation transfer. It is obvious that an increase in the radiation parameter results in decreasing velocity, cross flow velocity and temperature within the boundary layer.

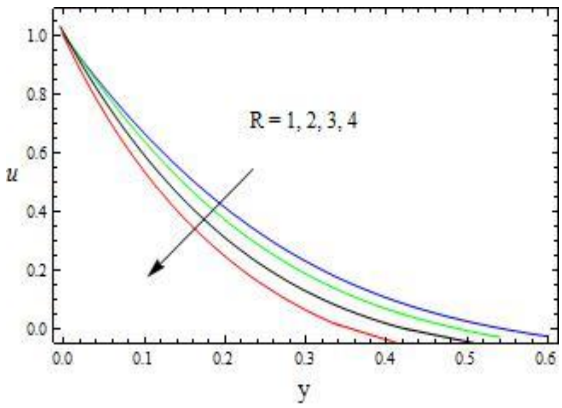


**Fig. 4.** The velocity Profile with *R*

The variation of velocity for distinct quantities of non-dimensional time t and Prandtl quantity Pr is displayed in the Figures 5 and 6. This is notified that magnitude of velocity are enhancing by an escalating in the time t. A velocity with time profile shows how velocity changes over time. The slope, equal to rise over run, is equal to the acceleration of the object. Acceleration is the change in velocity over time. The velocity versus time profile is equal to displacement, the difference in position between the start and end.

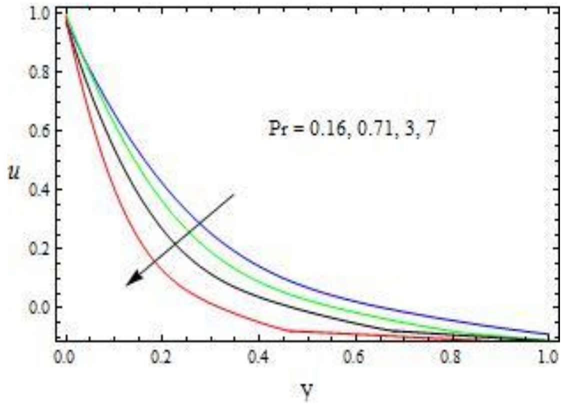


**Fig. 5.** The velocity Profile with Pr

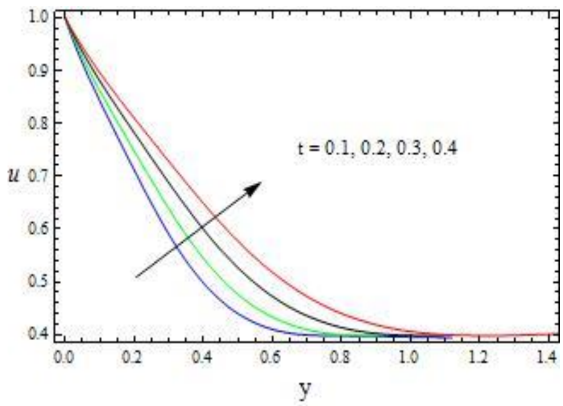


**Fig. 6.** The velocity Profile with *t*

This is also found that, from the Figure 6, the magnitude of the velocity reduces by an enhancing into the Prandtl number Pr. The Prandtl quantity actually described as the connection between momentum diffusion as well as thermal diffusion and hence control the relative thickness of the momentum and the thermal boundary layer. In the context of boundary layer flow, the Prandtl number correlates the thickness of the velocity boundary layer with that of the thermal boundary layer. A smaller Prandtl number signifies that thermal diffusion occurs faster than momentum diffusion, resulting in a thicker thermal boundary layer. The Prandtl number is an example of a dimensionless number that is an intrinsic property of a fluid. Fluids with small Prandtl numbers are free-flowing liquids with high thermal conductivity and are therefore a good choice for heat conducting liquids. The liquid metals are very good heat transfer liquids. Interestingly, air is a decent heat transfer liquid as well, whereas typical organic solvents are not. With increasing viscosity, the momentum transport dominates over the heat transport, which makes these liquids a bad choice for heat conduction.

Figs. 7 as well as 8 depicted the impact of the temperature Grashof quantity Gr and the mass Grashof quantity Gm on the velocity. A rise in the temperature Grashof number Gr and the accumulation Grashof quantity Gm contributes to a corresponding increase in the velocities magnitudes.

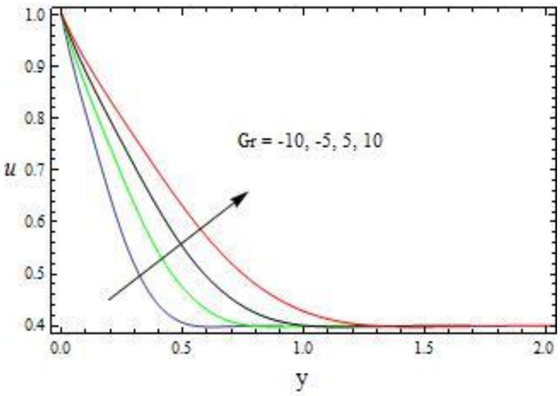


**Fig. 7.** The velocity Profile with Gr

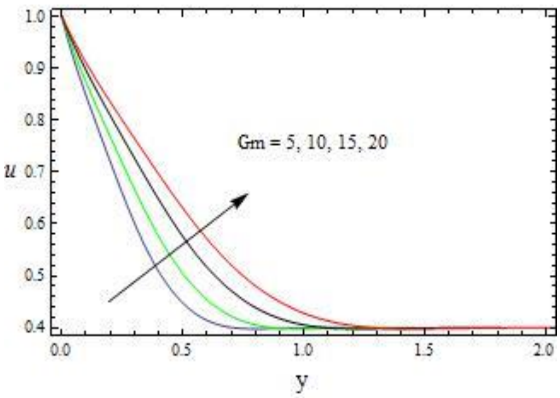


**Fig. 8.** The velocity Profile with Gm

Because buoyancy forces operate on the liquid particles in a way that is compatible with gravitational force, the momentum of the fluids is increased. These tendencies may be explained by the fact that the positive Grashof number Gr functioned in a manner analogous to the advantageous pressure gradients; these go faster the liquids into the border layer. Since a direct consequence, there is a rise in Gr, which led to an increase in velocity. Grashofs number reflects the impacts of freed convective currents. Gr > 0 denotes the warmth of the fluids of cooling of the boundary surface, Gr < 0 indicates the cool of the fluids of the warmth of the boundary surface, and Gr = 0 corresponds to the lack of liberated convective currents. Those conclusions were also utilized to study temperature as well as accumulations transfer in industrially, mechanically, along with aeronautical engineering, respectively. Therefore, the Figure 8 revealed that, the magnitude of the velocity enhance by an increasing in mass Grashofs quantity Gm in the complete fluid region.

Similarly the similar phenomenon is found by an increasing into Schmidt number (Fig.9). The Schmidt number (Sc) of a fluid is a dimensionless number defined as the ratio of momentum diffusivity (kinematic viscosity) and mass diffusivity, and it is used to characterize fluid flows in which there are simultaneous momentum and mass diffusion convection processes. It physically relates the relative thickness of the hydrodynamic layer and mass-transfer boundary layer.

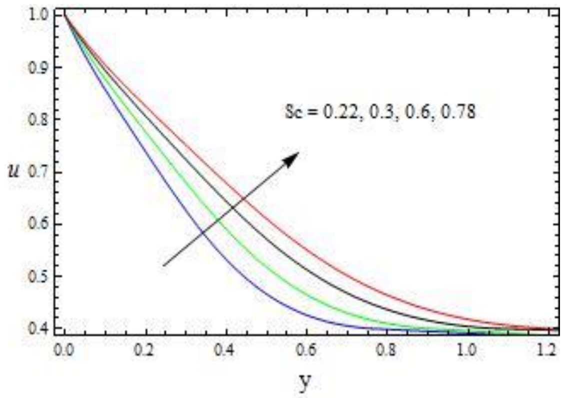


**Fig. 9.** The velocity Profile with Sc

The consequences of the radiating parameter R on the temperatures profiles was displayed into the Fig. 10. This was determined that, the temperature being as reducing functions of radiating, slow down the fluid movement and lessen the liquid velocity. Such a consequence might also be anticipated; here as escalating the radiation parameter R made the fluids thicker and eventually sources the temperature and thermal boundary layer thickness to reduce. Hence, there is found that, the temperature reduce by an increasing into the radiation parameter R complete fluid area.

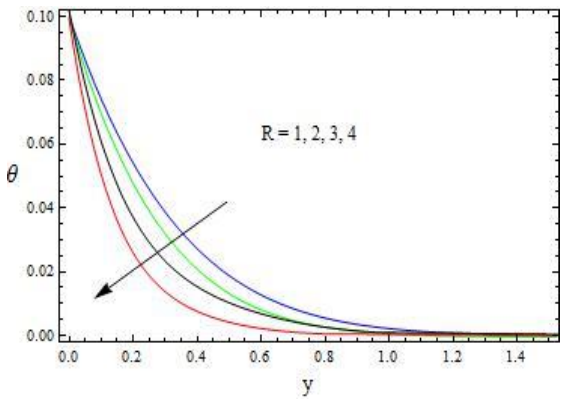


**Fig. 10.** The Temperature Profiles for $\theta$ with R

From Figure 11 it is found that, the temperature decreases by an enhancing the quantities of Prandtl quantity Pr, this was also found that, the thermally boundary layered thickness is maximum at the plate and reduces by an growing distance from foremost edge and finally approaches to vanish. This is also warranted owing to the fact that thermal conductivity of the fluids trim down by a growing in the Prandtl quantity Pr and hence it reduces the thermal boundary layers and the temperature profiles.

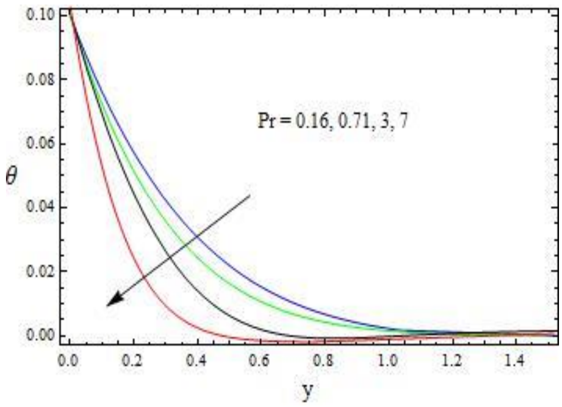


**Fig. 11.** The Temperature Profiles for $\theta$ with Pr

The Figure 12 depicted that, the concentration profiles with Schmidt number Sc leads to retardation sense throughout the liquid regions. As the Schmidt number increases, the mass transfer rate increases and hence the concentration profiles decreases. It is also utilized to characterizing the fluid flow in which there are simultaneously momentum and mass diffusion convective process.

The computational quantities of the skin friction (τ), Nusselt number (Nu) and Sherwood number (Sh) are found and they tabulated in the tables 1-3 in all those tabulated values the comparison of each and every parameters are making with initial row in the analogous table. These determined in the table 1, the effect of each and every parameters onto the skin friction shown that, the stresses are enhancing by an enhancing in radiation parameter, penetrability parameter, Prandtl number, thermal Grashof number, mass Grashof number, Schmidt number and some instant of time t, whereas it reduces with the Hartmann number M and for negative values of thermal Grashof number. It is also found by table 2 that Nusselt number Nu increases with increasing in radiation parameter, Prandtl number, and some instant of time t. It is also found by table 3, it is also found that Sherwood number goes on enhancing by an enhancing in Schmidt number and some instant of time t. The results are validated and compared with the existing results of Hossain et al. [5] and represented in the Table 4. The outcomes are very good concurrence with the previous outputs.

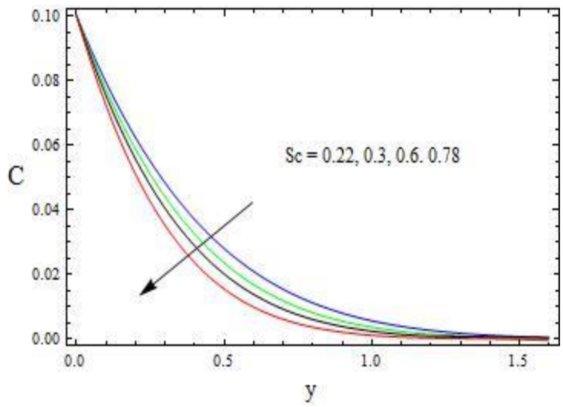


**Fig. 12.** The Concentration Profiles for C with Sc

**Table 1.** Skin friction

| *R* | *M* | *K* | Pr | Gr | Gm | Sc | t | τ |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 1 | 0.71 | 5 | 10 | 0.22 | 0.2 | 3.670424522152 |
| 2 | | | | | | | | 4.293540014287 |
| 3 | | | | | | | | 4.842449985698 |
| | 3 | | | | | | | 3.483381236554 |
| | 4 | | | | | | | 2.156285269856 |
| | | 2 | | | | | | 3.705316632562 |
| | | 3 | | | | | | 3.715524588985 |
| | | | 0.16 | | | | | 3.145449965896 |
| | | | 3 | | | | | 5.223574785548 |
| | | | 7 | | | | | 10.40940022546 |
| | | | | 10 | | | | 3.923577784591 |
| | | | | 15 | | | | 4.176710214587 |
| | | | | -10 | | | | 2.910999632546 |
| | | | | -15 | | | | 2.657857845965 |
| | | | | | 5 | | | 1.961789658966 |
| | | | | | 15 | | | 5.379060025285 |
| | | | | | 20 | | | 7.087707485596 |
| | | | | | | 0.30 | | 3.782563369859 |
| | | | | | | 0.60 | | 4.369331236548 |
| | | | | | | 0.78 | | 4.997034569960 |
| | | | | | | | 0.3 | 4.844663369859 |
| | | | | | | | 0.4 | 6.061658859745 |
| | | | | | | | 0.5 | 7.049607458898 |

**Table.2.** Nusselts number

| R | Pr | *T* | Nu |
|---|---|---|---|
| 1 | 0.71 | 0.1 | 0.195870145223 |
| 2 | | | 0.216376145288 |
| 3 | | | 0.235839589665 |
| 4 | | | 0.254358784456 |
| | 0.16 | | 0.107555422541 |
| | 3 | | 0.634710123654 |
| | 7 | | 1.393160114523 |
| | | 0.2 | 0.331442654112 |
| | | 0.3 | 0.461249441526 |
| | | 0.4 | 0.588593212563 |

**Table 3.** Sherwood number

| Sc | T | Sh |
|---|---|---|
| 2.0 | 0.1 | 0.104512122541 |
| 3.0 | | 0.226218411521 |
| 4.0 | | 0.356825123658 |
| 5.0 | | 0.493120745899 |
| | 0.2 | 0.147802125545 |
| | 0.3 | 0.181019652889 |
| | 0.4 | 0.209023325698 |
| | 0.5 | 0.233695112546 |

**Table 4.** Results comparisons for velocities with existing effects
($Pr = 0.71$; $Sc = 0.22$; $t = 0.2$)

| *R* | *M* | Gr | Gm | existing results Hossain et al. [5] | Current results $R \to 0$ |
|---|---|---|---|---|---|
| 1 | 2 | 5 | 10 | 0.364854145874 | 0.364854147852 |
| 2 | | | | 0.259854748554 | 0.259854458596 |
| 3 | | | | 0.168597857489 | 0.168597785479 |
| | 3 | | | 0.302551001428 | 0.302551785478 |
| | 4 | | | 0.261478452896 | 0.261478748596 |
| | | 10 | | 0.568950141748 | 0.568950748596 |
| | | 15 | | 0.768595789654 | 0.768595411258 |
| | | | 5 | 0.425789002145 | 0.425789001452 |
| | | | 15 | 0.587954785966 | 0.587954780025 |

## 4. Conclusions

We have explored the flows of the unsteady MHD convection flow during a loosely packed permeable media into a precipitately started perpendicular plate by the changeable temperature as well as mass transportation. The conclusions are completed as following.

1. The velocity reduces by an enhancing in the Hartmann quantity.
2. The magnitude of the velocity increase by an enhancing into the quantities of penetrability parameter.
3. The magnitude of the velocity are enhancing as well as it trim downs incessantly by an increasing into the radiating parameter.
4. The velocity is increasing by an increasing into the time.

5. The magnitude of the velocity decrease by an increasing in Prandtl number.
6. The velocity are reduces by an enhancing into the thermal Grashof number (freezing plates), while there itself sharps enhancements into velocity for heating of the plate.
7. The magnitude of the velocity is enhancing with an enhancing into the accumulation Grashofs quantity complete liquid area. The similar phenomenon is scrutinized by an increasing into Schmidt quantity Sc.
8. The temperature reduces by an increasing into the radiating parameters and/or Prandtl numbers.
9. The growing quantities of the Schmidt number led to descend the concentration profile complete liquid area.
10. Nusselts number is growing by an increasing into radiating parameter and Prandtl number.
11. The Sherwood number goes on increasing by an increasing into Schmidt quantity and instant of time.
12. This model can implemented for two or three dimensional flow, Hall and ion slip effects. This problem has been many applications in Biomedical engineering and Aerospace Engineering.
13. There are some limitations of this study, i,e, the model is applicable for only loosely packed porous medium

## Nomenclature

| | |
|---|---|
| $\beta$ | Volumetric coefficient of thermal expansion |
| $\beta *$ | Volumetric coefficient of expansion with concentration |
| $\sigma$ | Stefan–Boltzmann constant |
| $k$ | Permeability of porous medium ($m^2$) |
| $\rho$ | Density of the fluid (Kg $m^{-3}$) |
| $\theta$ | Dimensionless temperature |
| $\nu$ | Kinematic viscosity ($m^2s^{-1}$) |
| $\sigma$ | Electrical conductivity of the fluid ($sm^{-1}$) |
| $\tau$ | Dimensionless skin friction |
| $b$ | Similarity parameter |
| $a*$ | Absorption coefficient |
| $A$ | Constant |
| $B_0$ | External magnetic field ( $tesla$ ) |
| $C$ | Species concentration in the fluid (Kg $m^{-3}$) |
| $\overline{C}$ | Dimensionless concentration |
| $Cp$ | Specific heat at constant pressure ($K^{-1}m^2\ s^{-2}$) |
| $C_w$ | Concentration of the fluid (Kg $m^{-3}$) |
| $C_1$ | Concentration in the fluid far away from the plate (Kg $m^{-3}$) |
| $D_1$ | Chemical molecular diffusivity |
| $erf$ | Error function |
| $erfc$ | Complementary error function |
| $g$ | Acceleration due to gravity (m $s^{-2}$) |
| $Gm$ | Mass Grashof number |
| $Gr$ | Thermal Grashof number |
| $D$ | Darcy parameter |
| $k$ | Thermal conductivity of the fluid (W $m^{-1}$ $K^{-1}$) |
| $M$ | Magnetic field parameter |
| $Nu$ | Nusselt number |
| Pr | Prandtl number |
| $q_r$ | Radiative heat flux in the $y$ direction (W.$m^{-2}$) |
| $R$ | Radiation parameter |
| Sc | Schmidt number |
| Sh | Dimensional Sherwood number |
| $T$ | Temperature of the fluid near the plate (K) |
| $t$ | non-dimensional time |
| $\bar{t}$ | Dimensional time (s) |
| $T_w$ | Temperature of the fluid (K) |
| $T_1$ | Temperature of the fluid far away from the plate (K) |
| $u$ | Velocity of the fluid in the $x$ – direction (m $s^{-1}$) |

$u_0$ Velocity of the fluid (m s$^{-1}$)

$\bar{u}$ Dimensionless velocity

$y$ Coordinate axis normal to the plate (m)

$\bar{y}$ Dimensionless coordinate axis normal to the plate

Subscripts

$w$ Conditions on the wall

$\infty$ Free stream conditions

## Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article. In addition, the authors have entirely observed the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy.

## Appendixes

$$\xi = \frac{y}{2\sqrt{t}},$$

$$a_1 = 1 + \frac{\xi\, Pr}{\sqrt{Rt}},$$

$$a_2 = 1 - \frac{\xi\, Pr}{\sqrt{Rt}},$$

$$a_3 = \frac{R - \left(M^2 + \frac{1}{D}\right)}{1-\Pr},$$

$$a_4 = \frac{\left(M^2 + \frac{1}{D}\right)}{Sc - 1},$$

$$a_5 = \frac{1}{2}\left(a_9 + a_{10}\left(t - \frac{y}{2\sqrt{M^2 + (1/D)}}\right)\right),$$

$$a_6 = \frac{1}{2}\left(a_9 + a_{10}\left(t + \frac{y}{2\sqrt{M^2 + (1/D)}}\right)\right)$$

$$a_7 = \frac{a_{11}}{2}\left(1 + a_3 t - \frac{y a_3\sqrt{\Pr}}{2\sqrt{R/\Pr}}\right),$$

$$a_8 = \frac{a_{11}}{2}\left(1 + a_3 t + \frac{y a_3\sqrt{\Pr}}{2\sqrt{R/\Pr}}\right),$$

$$a_9 = 1 + a_{11} + a_{12},$$

$$a_{10} = \frac{Gr}{a_3(1-\Pr)} + \frac{Gm}{a_4(1-Sc)},$$

$$a_{11} = \frac{Gr}{a_3^2(1-\Pr)},$$

$$a_{12} = \frac{Gm}{a_4^2(1-Sc)}.$$

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