

Heat and Mass Transference Properties on Unstable MHD Movement past A Vertical Moving Plate In Presence Of Free Convection Through Finite Element Technique Solutions

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-----ABSTRACT-----

In this investigation we are concentrating on Finite state element method is worn toward analyses the arithmetical explanation for magneto hydrodynamic border layers. It is a mathematical study in which viscous incompressible electrical conductible magnetic fields have been examined through heat & mass move techniques. In this the plate is assumed as constant in velocity and getting the way of fluid flow through stream speed as considered to go after the exponentially raising preamble surface. The graphical representations of numerical results are shown as velocity, Temperature (TEMP) and the concentration of boundary layers. This work mainly connected with skin rubbing coefficient Nusslet as well as Sherwood records.

Keywords: Heat & Mass transfer; Free Convection; MHD; Limited Element Technique;

I. INTRODUCTION:

As of late, the investigation of hydro magnetic convection stream including Heat & mass exchange in permeable average has pulled in the consideration of numerous researchers on account of its potential requests in different pasture of science then innovation, for example, – soil sciences, astronomy, geophysics, atomic force reactors and so forth. In geophysics, it discovers its submissions in the structure of MHD producers also quickening agents, subversive water vitality stockpiling framework and so forth. It is worth-referencing that MHD is presently going through a phase of incredible extension and separation of topic. These new issues draw the deliberation of the scientists as of their changed centrality, in fluid metals, electrolytes and ionized gases and so forth. Joined impacts of Soret and Dufour consequences for temperamental hydromagnetic blended convective stream in a quickened vertical wavy plate through a permeable medium examined thru Aruna et al. [1]. Jithender Reddy and his co-workers ([2]-[9]) found the mathematical keys of heat & mass transmission fluid flow problems in existence of attractive field consuming finite component technique. Anand Rao & Srinivasa Raju ([10]-[12]) studied the Results of Soret, Dufour, Hall Current & viscous dissipation on an unsteady free convective fluid flow problem in occurrence of magnetic field, heat & mass transmission along a porous plate by means of finite element method. Anand Rao et al. ([13]-[20]) found the numerical solutions of unsteady free convective along a vertical and oscillatory plate embedded in porous medium in occurrence of heat & mass transfer, magnetic field, thermal radiation, Soret, Dufour, Hall current, rotation, heat source, heat absorption etc. Flimsy MHD free convection stream close on a vast vertical plate installed in a permeable medium by Chemical response, Hall Current also Thermal radiation concentrated thru Sarada et al. [21]. Sudhakar et al. ([22]-[24]) applied finite element technique on an unsteady magneto hydrodynamics free convective fluid flow along a vertical plate surrounded by porous average in attendance of chemical reaction, heat flux, Soret, Dufour, thermal radiation & viscous dissipation. Ramana Murthy et al. [25] contemplated heat & mass transmission impacts on MHD common convective stream past a limitless vertical permeable plate by warm radiation & Hall Current. Maddileti and Srinivasa Raju [26] found the mathematical arrangements of lobby impact on an insecure MHD free convective Couette stream among 2 porous plates utilizing limited component method. Ramya et al. ([27]-[29]) examined the impacts of speed, warm divider slips, concoction response, warm radiation and warmth age/retention on insecure free convective nanofluid stream over a Nonlinearly Isothermal Stretching Sheet in nearness of attractive field, warmth & mass exchange. Temperamental MHD blended convection stream past a vertical permeable plate in nearness of radiation concentrated through Sivaiah et al. [30]. Sivaiah & Srinivasa Raju [31] establish the mathematical answers of heat & mass transmission movement by hall existing, heat basis & viscous dissipation through applying finite element system. Synchronous impacts of warm radiation then turn consequences for an insecure MHD blended convection move through a permeable medium by Hall current & Heat ingestion explored by Venkataramana et al. [32]. Sheri et al. [33] examined fleeting magneto-hydrodynamic liberated convection stream past a permeable vertical plate in nearness of

goeey scattering. Rao et al. [34] contemplated the limited component examination of warm radioactivity& mass exchange stream p ast semi-interminable moving vertical plate by thick scattering. Dharmendar Reddy et al. ([35] and [36]) applied finite element technique on uneven magneto hydrodynamic open convective flow past a vertical porous plate through hall current, chemical response, heat & mass transfer.

Inspired by the above reference work and the various conceivable modern utilizations of the issue, it is of foremost enthusiasm for this examination to research the impacts of warmth & mass conversation on an insecure MHD stream along a permeable level plate. In this investigation, the impacts of various stream boundaries experienced in the conditions are additionally examined. The issue is tackled mathematically utilizing the limited component technique, which remains more prudent from the computational view point.

II. MATHEMATICAL FORMULATION:

Consider insecure 2-dimensional progression of a laminar, in compressible, thick, electrically leading liquid past a semi-limitless vertical penetrable stirring plate inserted in a consistent permeable average then exposed towards a uniform cross over attractive field within the sight of Soret&Dufour impacts. It is expected that there is no theoretical electrical energy which suggests the nonappearance of an electrical field. The transitionally practical attractive field then attractive Reynolds numeral remain assumed towards remain extremely little with the goal that the prompted attractive field then the Hall impact remain irrelevant. Additionally, in this work, Soret and Dufour impacts are likewise irrelevant. An outcome of the little attractive Reynolds numeral remains the uncoupling of the Navier-Stokes conditions as of Maxwell's conditions. The overseeing situations aimed at this examination be contingent on the equalizations of mass, direct force, vitality and fixation species. The attractive and goeey dispersals are ignored in this examination. The 3rd&4th conditions on the RHS of the power condition (2) signify the warm also focus lightness impacts, individually. It is accepted that the penetrable plate moves with a steady speed toward liquid stream, then the free stream speed follows the exponentially expanding. Likewise, it remains expected that the TEMP then the fixation at the divider just by way of the pull speed remain exponentially changing by time. Mulling over the suppositions made over, these situations can remain written in Cartesian edge of orientation by way of f

Equation of Continuity :

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

Momentum Equation:

$$\frac{\partial u'}{\partial t'} + v' \frac{\partial u'}{\partial y'} = -\frac{1}{\rho} \frac{\partial p'}{\partial x'} + \nu \frac{\partial^2 u'}{\partial y'^2} + g\beta_T(T' - T'_\infty) + g\beta_C(C' - C'_\infty) - \nu \frac{u'}{k} - \frac{\sigma}{\rho} B_0^2 u' \tag{2}$$

Energy Equation:

$$\frac{\partial T'}{\partial t'} + v' \frac{\partial T'}{\partial y'} = \alpha \frac{\partial^2 T'}{\partial y'^2} \tag{3}$$

Species Diffusion Equation:

$$\frac{\partial C'}{\partial t'} + v' \frac{\partial C'}{\partial y'} = D \frac{\partial^2 C'}{\partial y'^2} \tag{4}$$

The appropriate Boundary conditions for the velocity, temperature and concentration fields are

$$u' = u'_p ; T' = T'_w + \varepsilon(T'_w - T'_\infty)e^{nt}, C' = C'_w + \varepsilon(C'_w - C'_\infty)e^{nt} \text{ at } y' = 0$$

$$u' \rightarrow U'_\infty = U_0(1 + \varepsilon e^{nt}), T' \rightarrow T'_\infty, C' \rightarrow C'_\infty \text{ as } y' \rightarrow 0 \tag{5}$$

It is clear from equation (1) that the suction velocity at the plate surface is a function of time only. Assuming that it takes the following exponential form:

$$v' = -V_0(1 + \varepsilon A e^{nt}) \tag{6}$$

Where A is a real positive constant, ε and εA are small less than unity, and V_0 is a scale of suction velocity which has non-zero positive constant. Outside the boundary layer, equation(2) gives

$$\frac{-1}{\rho} \frac{dp'}{dx^2} = \frac{dU'_\infty}{dx} + \frac{\nu}{k} U'_\infty + \frac{\sigma}{\rho} B_0^2 U'_\infty \tag{7}$$

It is convenient to employ the following dimensionless variables:

$$u = \frac{u^1}{U_0}, v = \frac{v^1}{V_0}, y = \frac{v_0 y^1}{\nu}, U_\infty = \frac{U_\infty^1}{U_0}, U_p = \frac{u_p^1}{U_0}, t = \frac{t^1 \nu^2}{\nu}, \theta = \frac{T' - T_\infty^1}{T_w^1 - T_\infty^1}, \phi = \frac{c^1 - c_\infty^1}{c_w^1 - c_\infty^1}, n = \frac{n^1 \nu}{\nu_0^2},$$

$$k = \frac{k^1 \nu_0^2}{\nu^2}, P\gamma = \frac{\nu_p C_p}{k} = \frac{\nu}{\alpha}, s_c = \frac{\nu}{D}, M = \frac{\sigma B_0^2 \nu}{\rho \nu_0^2}, G_\gamma = \frac{\nu \beta_T g (T_w^1 - T_\infty^1)}{U_0 \nu_0^2}, G_C = \frac{\nu \beta_C g (C_w^1 - C_\infty^1)}{U_0 \nu_0^2} \tag{8}$$

In view of equations (6)-(8) and equations (2)-(4) reduce to the following dimensionless form:

$$\frac{\partial u}{\partial t} - (1 + \varepsilon A e^{nt}) \frac{\partial u}{\partial y} = \frac{dU_\infty}{dt} + \frac{\partial^2 u}{\partial y^2} + G_y \theta + G_c \phi + N(U_\infty - u) \quad (9)$$

$$\frac{\partial \theta}{\partial t} - (1 + \varepsilon A e^{nt}) \frac{\partial \theta}{\partial y} = \frac{1}{Pr} \frac{\partial^2 \theta}{\partial y^2} \quad (10)$$

$$\frac{\partial \phi}{\partial t} - (1 + \varepsilon A e^{nt}) \frac{\partial \phi}{\partial y} = \frac{1}{Sc} \frac{\partial^2 \phi}{\partial y^2} \quad (11)$$

The dimensionless form of the boundary conditions (5) and (6) becomes:

$$u = U_p, \theta = 1 + \varepsilon e^{nt}, \phi = 1 + \varepsilon e^{nt} \text{ at } y = 0 \text{ \& } u \rightarrow U_\infty, \theta \rightarrow 0, \phi \rightarrow 0 \text{ as } y \rightarrow \infty \quad (12)$$

The Skin-friction coefficient, the Nusselt FIG (Rate of warmth remove) and the Sherwood numbers (Rate of mass transmit) are significant physical limitations on behalf of this kind of border coating flow. These restrictions can be definite also resolute as follows:

$$\tau = \frac{\tau_w^*}{\rho \int_0^{\infty} v_0} = \left(\frac{\partial u}{\partial y} \right)_{y=0} \quad (13)$$

$$Nu = x \frac{\frac{\partial T'}{\partial y'} \Big|_{y'=0}}{(T_w^1 - T_\infty^1)} \Rightarrow Nu Re_x^{-1} = \frac{\partial \theta}{\partial y} \Big|_{y=0} \quad (14)$$

$$Sh = x \frac{\frac{\partial c'}{\partial y'} \Big|_{y'=0}}{(c_w^1 - c_\infty^1)} \Rightarrow Sh Re_x^{-1} \frac{\partial \phi}{\partial y} \Big|_{y=0} \quad (15)$$

Where $Re_x = \frac{v_0 x}{\nu}$ is the local Reynolds number.

III. FINITE ELEMENT METHOD MATHEMATICAL SOLUTIONS:

Limited Element Technique: The limited component system (FEM) remains a mathematical then PC base strategy for unraveling an assortment of viable building issues that occur in various fields, for example, in heat move, liquid mechanics ([37]-[66]) and numerous different fields. It is perceived by designers and buyers as one of the most compelling mathematical examination apparatuses ever formulated to investigate complex issues of building. The predominance of the strategy, its exactness, straightforwardness, and equivalence all make it a broadly utilized contraption in the building demonstrating and configuration measure. It has been applied to various considerable numerical models; whose differential conditions are settled by changing over them into a network condition. The essential component of FEM ([67] and [68]) is its capacity to depict the calculation or the media of the issue being broke down with tremendous adaptability. This is on the grounds that the optional of the locale of the issue remains achieved utilizing profoundly adaptable uniform otherwise non-uniform pieces then components that can without much of a stretch portray complex shapes. The technique basically comprises in accepting the piece shrewd consistent capacity for the outcomes and getting the boundaries of the capacities in a way that diminishes the issue in the arrangement. The means involved in the limited component investigation regions follows.

Stage 1: Discretionary of the Domain The central idea of the FEM remains towards isolate the locale of the issue hooked on little associated pieces, called limited components. The gathering of components is known as the limited component work. These limited components are related in a non-covering way, with the end goal that they totally spread the whole space of the issue.

Step 2: Invention of the Element Equations

- i) An agent component remains isolated from the work then the variation plan of the assumed issue remains made over the commonplace component.
- ii) Over a component, an inexact arrangement of the variational issue is imagined, and by surrogating this in the framework, the component conditions are created.
- iii) The component network, which is otherwise called solidness grid, is raised by utilizing the component addition capacities.

Stage 3: Assembly of the Element Equations the logarithmic situations consequently accomplished remain collected through forcing the bury component coherence situations. This yields countless numerical conditions known as the worldwide limited component model, which oversees the entire area.

Stage 4: obligation of the Boundary circumstances On the collected conditions, the Dirichlet's & Neumann limit situations (12) remain forced.

Stage 5: Answer of Assembled Equations The collected conditions thus acquired can remain comprehended through at all of the mathematical strategies, specifically, Gauss end method, LU deterioration strategy, then the last lattice condition can remain tackled through iterative procedure. on behalf of computational intention, the

synchronize y is numerous as of zero to $y_{\max}=\text{nine}$, y_{\max} where correspond to perpetuity i.e., exterior toward the impetus, power too deliberation aspect layers.

In one-dimensional freedom, straight & quadratic components, otherwise component of higher request can remain taken. The whole stream region remains partitioned hooked on 11000 quadratic components of equivalent size. Every component remains three-noded, too hence the entire space contains 21001 hubs. At every hub, four capacities remain towards remain assessed; subsequently, after get together of the component conditions, we get an arrangement of 81004 conditions which are nonlinear. Hence, an iterative plan must remain created in the arrangement. In the wake of striking the limit conditions, an arrangement of conditions has been gotten which is unraveled numerically by the Gauss end strategy while keeping up an accuracy of 0.00001. A union standard dependent on the relative contrast between the present and going before cycles is utilized. At the point when these distinctions fulfill the ideal rightness, the arrangement is expected towards consume remained congregated also iterative cycle remains ended. The Gaussian quadrature remains applied aimed at fathoming the reconciliations. The PC cryptogram of the calculation consumes remained acted in MATLAB running on a PC. Magnificent union remained finished aimed attentively the outcomes.

IV. RESULTS AND DISCUSSIONS:

The likeness conditions (9), (10) and (11) were illuminated mathematically dependent upon the limit conditions given through (12). Graphical portrayals of the mathematical outcomes remain shown in FIG (1) through Fig (8) towards demonstrate the impacts of various statistics on the limit coating stream. In this examination, we explore the impact of the impacts of material boundaries, for example, Prandtl number, Schmidt number, Hartmann number, Grashof number, Modified Grashof number and Permeability boundary independently so as to obviously watch their separate consequences for the speed, TEMP and focus outline of the stream. Likewise, Skin-grinding coefficient, speed of warmth also mass exchange coefficients as far as Nusselt number & Sherwood number individually consume remained seen through graphically. Throughout mathematical estimations of the speed, TEMP also focus, the estimations of the Prandtl number remain picked aimed at Mercury ($Pr = 0.025$), Air at 25oC too one climatic weight ($Pr = 0.71$), Water ($Pr = 7.00$) then Methanol ($Pr = 11.62$). To concentrate on mathematical estimations of the outcomes acquired in the examination the estimations of Sc remain picked aimed at the gases speaking to diffusing synthetic types of most normal enthusiasm for air to be specific Hydrogen ($Sc = 0.22$), Helium ($Sc = 0.30$), Water-fume ($Sc = 0.60$) also Oxygen ($Sc = 0.66$). For the physical hugeness, the mathematical conversations in the issue too at $t = 1.0$, stable qualities aimed at speed, TEMP & focus fields are gotten. To analyze the impact of boundaries identified with the issue on the speed field & Skin-grating mathematical calculations remain completed at $Pr = 0.71$. To discover arrangement of this issue, we consume put a vast vertical plate in a limited distance end to end in the stream. Henceforth, we take care of the whole issue in a limited limit. Notwithstanding, in the charts, the y esteems differ from 0 to 9, then the speed, TEMP, also fixation will in general zero as y watch out for 9. This is valid aimed at all estimation of y . Hence, we have thought about limited length.

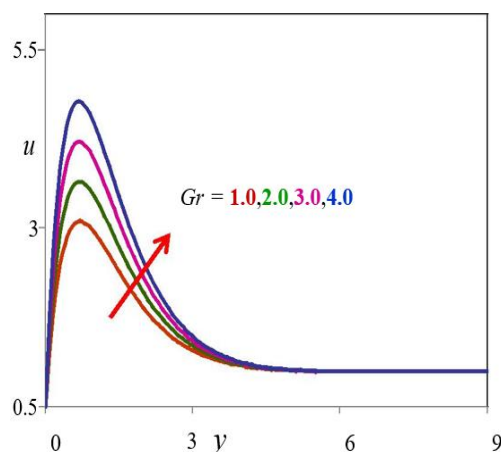


Fig. 1. Result of Gr on rapidity profiles

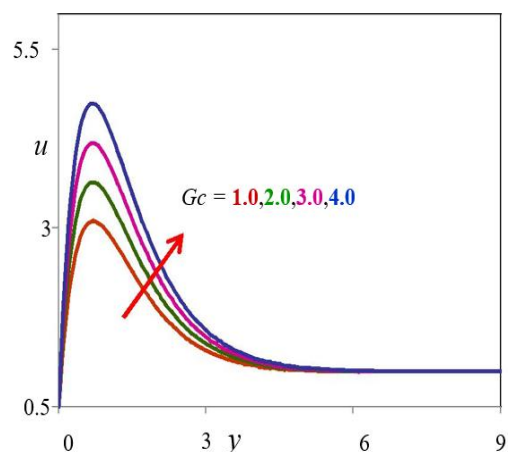


Fig. 2. Result of Gc on Velocity profiles

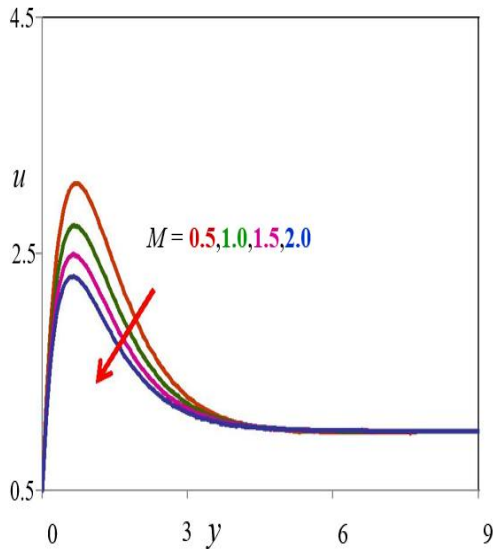


Fig. 3. Result of M on Velocity profiles

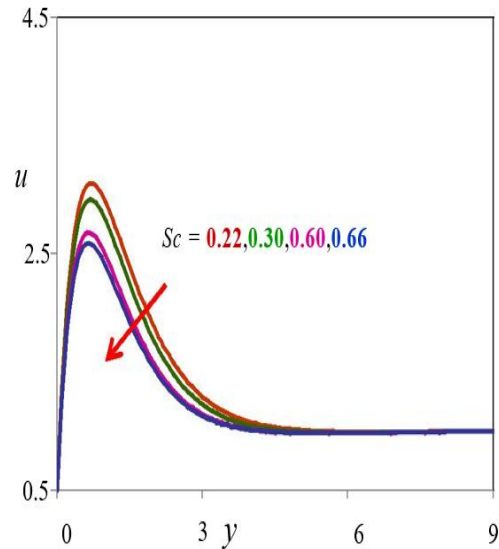


Fig. 4. Result of Sc on Velocity profiles

4. 1. Results and Discussions of Velocity Profiles:

The TEMP then the species fixation remains coupled towards the speed through Grash of number & Modified Grash of number by way of found in condition (9). FIGs (1) - (6) show the impacts of material boundaries, for example, Gr, Gc, Sc, Pr, M and K. For different estimations of Grash of number & customized Grash of FIG, the speed outline is plotted in statistics (1) & (2). The Grash of FIG means the overall impact of the warm lightness power towards the gooey hydrodynamic power in the limit layer. True to form, it remains seen that there is an ascent in the speed because of the upgrade of warm lightness power. Likewise, as Gr expands, the pinnacle estimations of the speed increment quickly close to the permeable plate and afterward rots easily to the free stream speed. The Modified Grash of numeral characterizes the proportion of the species lightness power towards the gooey hydrodynamic power. True to form, the liquid speed increments and the pinnacle esteem is more unmistakable because of increment in the species lightness power. The speed appropriation achieves an unmistakable most extreme incentive in the region of the plate then afterward diminishes appropriately towards move toward the free stream esteem. It remains seen that the speed increments by expanding estimations of the Modified Grash of numeral. The impact of the Hartmann number remains appeared in FIG (3). It remains seen that the speed of the liquid reductions by the expansion of the attractive field number qualities. The lessening in the speed by way of the Hartmann number increments remains on the grounds that the nearness of an attractive field in an electrically leading liquid presents a power called the Lorentz power, which acts against the stream if the attractive field remains applied the typical way, by way of in the current examination. This resistive power hinders the liquid speed part by way of appeared in FIG (3). The idea of speed profiles in nearness of unfamiliar species, for example, Hydrogen ($Sc = 0.22$), Helium ($Sc = 0.30$), Water-fume ($Sc = 0.60$) & Oxygen ($Sc = 0.66$) remain appeared in FIG (4). The stream field endures an abatement in speed on entirely focuses in nearness of heavier diffusing species. FIG (5) portrays the impact of Prandtl number on speed profiles in nearness of unfamiliar species, for example, Mercury ($Pr = 0.025$), Air ($Pr = 0.71$), Water ($Pr = 7.00$) then Methanol ($Pr = 11.62$) remain appeared in FIG (5). We see that from FIG (5) the speed diminishes by expanding of Prandtl numeral. In FIG (6) we have the impact of the Permeability boundary on the speed. It tends to remain considered that to be the estimations of this boundary expands, the speed increments.

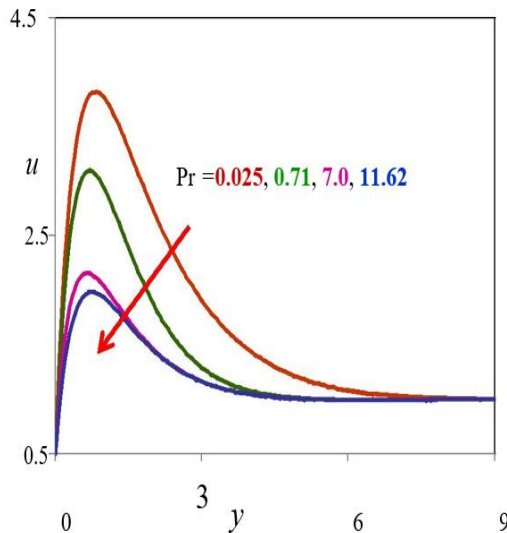


Fig. 5. Result of Pr on Velocity profile

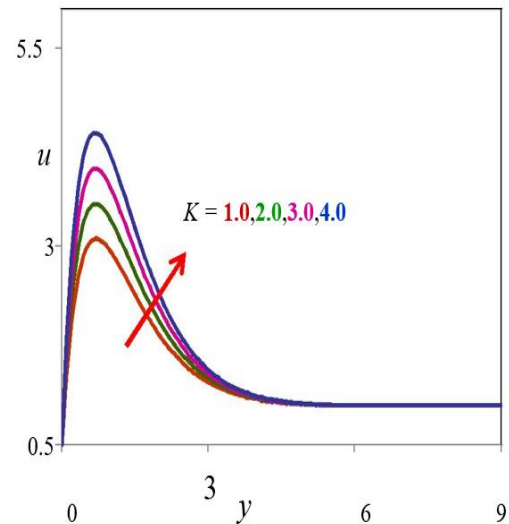


Fig. 6. Result of K on Velocity profiles

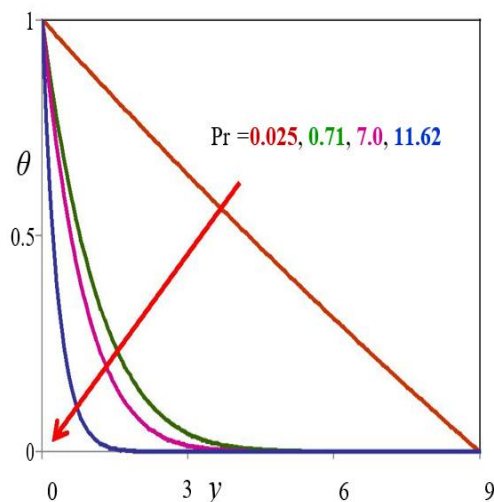


Fig. 7. Result of Pr on TEMP profiles

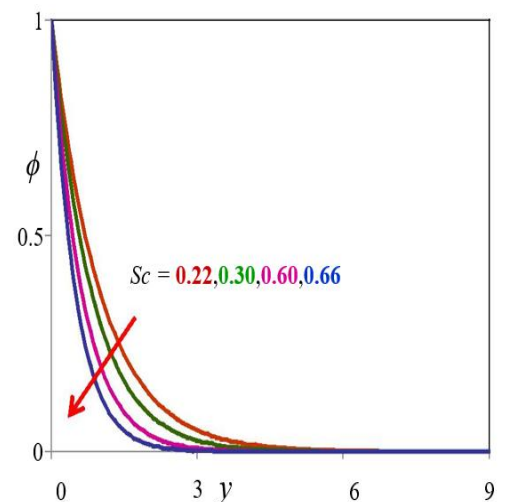


Fig. 8. Result of Sc on Concentration profiles

4. 2. Results and Discussions of TEMP Profiles:

In FIG (7) we delineate the impact of Prandtl number on the TEMP field. It remains seen that an expansion in the Prandtl numeral prompts decline in the TEMP field. Additionally, TEMP field falls all the further quickly aimed at water in contrast with air then the TEMP bend is actually straight aimed at mercury, which remains more reasonable to modification in TEMP. From this perception it remains infer that mercury is best aimed at keeping up TEMP contrasts then can remain utilized Resultively in the research center. Air can supplant mercury, the adequacy of keeping up TEMP variations remain substantially less than mercury. Nonetheless, air can remain well too modest substitution aimed at mechanical reason. This remains on the grounds that, either increment of kinematic consistency or decline of warm conductivity prompts increment in the estimation of Prandtl numeral. Subsequently TEMP diminishes by expanding of Prandtl number.

4. 3. Results and Discussions of Concentration Profiles:

The impact of Schmidt number on the focus field is introduced in FIGs (8). FIG (8) demonstrations the fixation field because of variety in Schmidt numeral aimed at the gasses Hydrogen, Helium, Water-fume & Oxygen. It remains seen that fixation field remains consistently aimed at Hydrogen & falls quickly aimed at Water-fume too Oxygen in contrast with Helium. Hence, Hydrogen can be utilized for keeping up powerful focus field and Helium can be utilized for keeping up ordinary fixation field.

Table-1: Skin-friction coefficient (τ)

Gr	G_c	M	K	Pr	Sc	τ
1.0	1.0	1.0	1.0	0.71	0.22	0.2161
2.0	1.0	1.0	1.0	0.71	0.22	0.2314
1.0	2.0	1.0	1.0	0.71	0.22	0.2406
1.0	1.0	2.0	1.0	0.71	0.22	0.1513
1.0	1.0	1.0	2.0	0.71	0.22	0.2615
1.0	1.0	1.0	1.0	7.00	0.22	0.2148
1.0	1.0	1.0	1.0	0.71	0.30	0.2116

4. 4. Results and Discussions of Skin-friction Coefficient:

The profiles for Skin-rubbing due to velocity under the influences of Grash of range, Modified Grash of numeral, Hartmann quantity, Permeability boundary, Prandtl quantity and Schmidt quantity is added within the table-1. We see as of the above table-1, the Skin-erosion due to pace increments below the impacts of Grashof number, Modified Grashof variety, Permeability boundary and diminishes below the influences of Hartmann range, Prandtl quantity and Schmidt quantity.

4. 5. Results and Discussions of Nusselt & Sherwood Numbers:

The profiles aimed at Nusselt numeral because of TEMPprofile under the impact Prandtl number remains introduced in the table-2. We getas of this table-2 the Nusselt numeral because of TEMP falls under the impact of Prandtl number. The profiles aimed at Sherwood number because of focus profiles under the impact of Schmidt number remains introduced in the table-2. We see from this table the Sherwood number because of fixation profile falls under the impact of Schmidt number.

Table-2: Nusselt number & Sherwood number

Pr	Nu	Sc	Sh
0.71	4.8586	0.22	7.5597
7.00	4.4782	0.30	7.3401
11.62	3.3719	0.78	6.3932

V. CONCLUSIONS:

This work researched a precarious MHD stream past a semi-unending vertical moving porous moving plate by heat move also mass exchange. The overseeing conditions are approximated to an arrangement of straight conventional differential conditions by utilizing reasonable closeness changes. Mathematical counts are done for different estimations of the dimensionless quantities of the issue utilizing a proficient and limited component technique. The outcomes are introduced graphically then we can presume that the stream field then the amounts of physical intrigue remain altogether affected thru these numbers.

1. The speed increments by way of the porousness boundary, warmth and mass exchange increments. In any case, the speed remained found towards diminishes by way of the Hartmann numeral, Prandtl numeral& Schmidt numeral are increments.
2. The liquid TEMPremained found towards diminish by way of the Prandtl numeral increments.
3. The focus diminishes by way of the Schmidt numeral increments.
4. The Skin-erosion coefficient because of speed profile increments below the impacts of Grashof number, Modified Grashof number and Permeability boundary too diminishes below the impacts of Hartmann number, Prandtl number and Schmidt number.

5. Nusselt numeral due TEMP profile falls under the impact of Prandtl numeral.
6. Sherwood numeral due fixation profile falls under the impact of Schmidt numeral.

Nomenclature:

List of Variables:

A	Suction velocity parameter
C'	Concentration of the fluid
B_0	Magnetic induction
C_P	Specific heat at constant pressure
D	Mass diffusion coefficient
g	Acceleration due to gravity
Gc	Grash of number
Gr	Modified Grash of number
K	Permeability of the porous medium
k	Thermal conductivity
n	Dimensionless exponential index
t	Dimensionless time
M	Hartmann number
Re_x	Local Reynolds number
Nu	Nusselt number
Pr	Prandtl number
Sc	Schmidt number
Sh	Sherwood number
u, v	Components of velocities along and perpendicular to the plate, Respectively
T'	Temperature

x, y Distances along and perpendicular to the plate, respectively

U_0 Scale of free stream velocity

V_0 Scale of suction velocity

Greek symbols:

ϕ Dimensionless concentration

β_c Coefficient of volumetric concentration expansion

β_T Coefficient of volumetric thermal expansion

θ Dimensionless temperature

ρ Fluid density

μ Fluid dynamic viscosity

σ Fluid electrical conductivity

ν Fluid kinematic viscosity

α Fluid thermal diffusivity

ϵ Scalar constant ($\ll 1$)

τ Skin-friction coefficient

Superscripts:

$'$ Dimensionless Properties

Subscripts:

p Plate

w Wall condition

∞ Free stream condition

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