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EFFECTS OF A MAGNETIC FIELD ON CIRCULATION IN AN ADVANCED INCLINED ISOTHERMAL SECTIONAL SURFACE WITH MASS AND HEAT TRANSFER

M. Sundar Raj[1*], G. Nagarajan[1], R. Rajaraman[2], B. Saravanan[3] and R. Muthucumaraswamy[3]
[1]Mathematics, Panimalar Engineering College, INDIA
[2]Mathematics, R.M.K. Engineering College, INDIA
[3]Applied Mathematics, Sri Venkateswara College of Engineering, INDIA
E-mail: sundarrajkani@gmail.com

The purpose of this study is to investigate the influence of an external magnetic field on heat and mass distribution across a moving isothermal sectional surface. The temperature is elevated to (E_{ω}) of the plate. The proximity intensity is increased to the concentration of the plate (L'_{ω}). The study addresses a range of physical factors, including time, velocity profile, temperature, and intensity, as well as thermal Grashof number (T_g), mass Grashof number (T_m), Schmidt number (Sc), and Prandtl number (P_r). The dimensionless equations are addressed using both the Laplace-transform technique and the finite difference method, which is used to analyze the energy, momentum, and concentration equations. The results are illustrated through graphical representations, and the tabular manner to showcase various flow parameters. The results indicate that the velocity increases proportionally with changes in (T_g) and (T_m). As the angle (α) rises, the velocity shows a clear incremental pattern when the magnetic field strength decreases. Local skin friction correlates positively with the angle (α), Sc, and Pr, and negatively with Gr, Gc, and time. The study includes a Nusselt number table for various parameters corresponding to an increase in the Prandtl number, as well as the Sherwood number for different components as the Schmidt number escalates. This work helps us learn more about the complicated interactions between magnetic fields and fluid movement, which is useful for many engineering and science projects.

Key words: accelerated vertical plate, heat and mass transfer, isothermal, inclined plate, mass diffusion.

1. Introduction

Inclined isothermal sectional surfaces have several advantages, such as improved efficiency, reduced costs, and prolonged device longevity. These surfaces play a significant role in enhancing operating efficiency, reducing expenses, and extending the functioning of devices. Numerous disciplines make use of Magnetohydrodynamics (MHD), from agriculture and oil exploration to geology and even astronomy. It is also employed in the study of geological structures, the search for oil, the recovery of heat, the evaluation of reservoirs and hydrothermal basins, and the detection of buried nuclear waste. MHD also has important applications in metrology, astromechanics, planetary aerodynamics, molecular research, and technology. Because of its potential to increase thermal efficiency in power facilities, MHD is attracting a growing amount of attention in the power production industry. Several factors regarding a cutting-edge perpendicular unbounded surface with varied emission modalities were investigated by Raptis *et al.* [1, 2]. Free convection movement was also examined over a vertically accelerated surface. Basanth and Ravindra [3] analyzed the free convection and mass transfer past an AVP subjected to heat inputs. Transient ordinary convection circulation with external temperature changes was solved numerically by Ganesan and Ekambavanan [4]. Using Heat and Mass Transfer (HMT), Muthukumaraswamy and Ganesan [5] analyzed asymmetrical flow in an AVP. Unsteady MHD convection was investigated by Kamel [6] in a permeable material with coupled HMT and a heat source/sink. Using a variety of concentrations and temperatures, Chen [7] studied typical heat transmission on an incline exterior. Mbeledogu *et al.* [8] explained how a fluid with a subjective temperature

[*] To whom correspondence should be addressed

distribution might move across a moving VP due to natural convection. Suneetha *et al.* [9] investigated how heat radiation affected MHD spontaneous convective circulation through an AVP subject to varying external temperature and intensity. These investigations aid in expanding our knowledge of MHD's potential in a wide range of scientific and technological fields.

Sundar Raj *et al.* [10] examined the implications of thermal transmission on an AVP. Eldabe *et al.* [11] explained the liquid irregular motion containing a heat transfer medium as it passed through a permeable material in conjunction with a mechanical vapor recompression (MVR) system. Kumar and Varma [12] investigated the influence of heat transfer on magnetohydrodynamics in the context of a spontaneously generated AVP, amidst temperature variation in the area of thermal production. The influence of an inconsistent magneto hydrodynamic unbounded convective circulation across a perpendicular perforated surface amongst suction or injection was examined by Shivaiah and Anandrao [13]. Pattnaik *et al.* [14] investigated the effects of heat transmission on the natural convection circulation of a magnetohydrodynamic flow in an exponential axial velocity profile. The study focused on a permeable substance with varying temperatures. Mishra *et al.* [15] examined the influence of heat transmission on the movement of a viscoelastic liquid through a permeable medium, considering periodic pressure and thermal supply. Alam and Hossain [16] investigated the heat and mass transfer in a natural convective circulation driven by Magnetohydrodynamics across an inclined plane (IP) in the presence of Hall current. Muthucumarswamy and Jeyanthi [17] explored the Hall effects on magnetohydrodynamic (MHD) flow over an infinite vertical plate in a rotating fluid with variable temperature and uniform mass diffusion, incorporating a first-order chemical reaction. Barik *et al.* [18] studied the effects of heat exposure on an unstable MHD system using an angled permeable warmed plate within synthetic reaction and elastic dispersion. Das *et al.* [19] investigated the mixed convective slippage movement in an MHD across a sloped permeable surface. The investigation incorporated elastic dispersion and joule activation. The thermal transmission ramifications of a diffusive liquid flow traveling through a surface were explored by Raju *et al.* [20]. Suriyakumar and Anjali [21]investigated the effects of pull and interior thermal production on the movement of hydromagnetic blended convective nanofluid across a slanted elongating panel. Sheri *et al.* [22] investigated the impact of mass and heat exchange phenomenon on the movement of magnetohydrodynamics convection across an infinitely inclined surface. Muthucumaraswamy and Sivakumar [23] examined the MHD flow over an infinite isothermal vertical plate with a parabolic velocity profile, considering the effects of thermal radiation and a chemical reaction.The effects of magnetohydrodynamic movement across an AIP with a heating rate were analyzed by Pattnaik *et al.* [24]. Gaurav [25] explained an analysis of the magnetohydrodynamic flow over a sloped surface in motion, taking into consideration the presence of mass transmission. The influences of twisting and radiative phenomena on magnetohydrodynamic circulation across an inclined panel subjected to variable boundary temperature and mass transfer, in the Hall current were studied. Thirupathi *et al.* [26] investigated the convection of magnetohydrodynamic nanofluids from an inclined surface subjected to alternating thermal conditions, including radiative flux, thermal supply, and variable temperature effects using finite element analysis. The influence of unsteady movement in a permeable environment was examined by Gaurav and Rajput [27] using an Artificial Intelligence Planner (AIP) with adjustable settings. Rajput and Gaurav [28] further investigated the effects of rotation and radiation on magnetohydrodynamic circulation across an inclined surface with variable wall temperature and mass dispersion, incorporating Hall current. Endalew and Nayak [29] examined the effects of heat irradiation and a sloping magnetic field on the magnetohydrodynamic flow across a progressive artificial intelligence platform in a permeable material with temperature variations. Prakash *et al.* [30] investigated a unique nanopump design that uses solar energy as its power source. Prusty and Senapati [31]studied the characteristics of an unsteady magnetohydrodynamic and heat and mass transfer process involving a liquid flowing from a source across an Axisymmetric Inclined Porous Plate (AIPP), taking into account the presence of hall current in the region. Sandhya *et al.* [32] explained the effects of temperature and weight transfer on the flow characteristics of a perforated surface at an angle. Joshi *et al.* [33] conducted a numerical study of three-dimensional magnetic hybrid nanofluid flow (SWCNT + Ag–H_2O) over a porous, bidirectional stretchable surface, considering the effects of a higher-order chemical reaction, internal heat generation, and mixed convection. The study explored heat transfer, mass diffusion, and fluid flow characteristics across various parameter ranges, including porosity parameter $\left(0.5 \le K \le 1.2\right)$, Hartmann number $(0.2 \le Ha \le 1)$, internal heat generation $(0.1 \le H \le 1)$, thermal Grashof number $(0.1 \le Gr \le 0.4)$, mass Grashof number $(0.1 \le Gc \le 0.4)$, Schmidt number $(0.2 \le Sc \le 1)$, chemical reaction parameter $(0.5 \le Y \le 3)$, and chemical reaction order $(1 \le q \le 4)$, with a fixed nanoparticles' volume fraction and Prandtl number for power index numbers $n = 1$ and 2. Fatunmbi and Salawu [34] conducted a numerical investigation of a hydromagnetic, dissipative micropolar nanofluid flow model influenced by multiple slip conditions and mass flux. Additionally, they examined the entropy generation within the conducting, chemically reactive micropolar nanofluid in a permeable medium, considering the effects of thermophoresis and Brownian motion on the model.

Zafar *et al.* [35] investigated the fluid flow without the presence of a magnetic field through an inclined surface with varying thermal characteristics. Dadheech *et al.* [36] investigated the phenomenon of entropy in the context of photonic angled magnetohydrodynamic slipping movement, incorporating a heating element within a permeable substance. They focused on two different liquids during their investigation. Preeti and Mishra [37] examined the evaluation of entropy in the context of a radiation-angled magnetohydrodynamic slip flow within a permeable medium, considering two distinct liquid substances. Nagarajan *et al.* [38] investigated the impact of heat inflation on the flow through an orientated advanced sectional surface with sustained mass dispersion. Vishalakshi *et al.* [39] investigated the behavior of a magnetohydrodynamic fluid flowing through a porous surface, incorporating slip and mass transpiration. Nayak *et al.* [40] researched the auto-analytic reactions aimed at minimizing entropy. Bharathi *et al.* [41] examined the impact of tilt, electromagnetic field strength, and variable conductance on the phenomenon of spontaneous convective motion occurring over an infinitely large, perpendicular, and permeable surface. Sundar Raj *et al.*[42] analyzed the impacts of chemical reactions on an inclined isothermal vertical plate. Weirong Xiu *et al.*[43] focused on the combined effects of Lorentz force, micro-rotation, and particle thermo-migration on the dynamics of micropolar fluids subjected to nonlinear thermal radiation and Arrhenius chemical reactions related to activation energy. The study examined the flow of a reactive non-Newtonian, magneto-micropolar nanoparticle fluid over a specially configured two-dimensional stretchy vertical plate. This flow was influenced by activation energy, Brownian motion of small particles, particle thermo-migration, and nonlinear thermal radiation. Upreti *et al.* [44] examined the flow attributes of Au–TiO_2/ethylene glycol hybrid nanofluid flowing over a thin needle. The fluid flow was exposed to a uniform magnetic field, and fluid properties (dynamic viscosity and thermal conductivity) were considered to be temperature and nanoparticle shape-dependent. In addition, the effect of quadratic convection with quadratic thermal radiation was investigated, and the process of heat transfer was explicated using the Cattaneo-Christov heat flux model. Salawu [45] investigated the effects of thermo-diffusion and diffusion-thermo interactions on the motion of a hydromagnetic reacting micropolar fluid along an elongated surface with lateral mass flux in porous media. This study also reported on the thermophoretic phenomenon, along with the impacts of viscous dissipation and heat sources. A three-dimensional Darcy-Forchheimer flow model and the heat transfer behavior of an H_2O-CNT nanofluid over a bidirectional stretchable surface, using Xue's proposed thermal conductivity model was investigated by Upreti *et al*. [46]. The study observed that as the Eckert numbers increased in both directions, the temperature profiles initially rose before eventually decreasing. Additionally, the thermal boundary layer thickness was greater for the H_2O-MWCNT nanofluid compared to the H_2O-SWCNT nanofluid. Fatunmbi *et al.* [47] investigated the mechanism of melting heat propagation in the motion of a micropolar fluid over a stretching electromagnetic actuator (Riga plate) with variable sheet thickness. The fluid contains nanoparticles and is influenced by an uneven heat source, radiation, thermophoresis, random motion of the nanoparticles, and variable thermal conductivity. Upreti *et al.* [48] studied the effects of the quadratic Boussinesq approximation and quadratic thermal radiation on the heat transfer analysis of magnetized Sisko nanofluid flow with Cattaneo-Christov (CC) heat flux over a stretching surface, using response surface methodology (RSM). Heat transfer and skin friction calculations were performed for various parameters, including the magnetic field, Eckert number, Forchheimer parameter, thermal relaxation parameter, radiation parameter, porosity parameter, and Biot number. For sensitivity analysis, the response surface method with a Face-Centered Central (FCC) design was applied. Alao *et al.* [49] examined the effects of energy sources and sinks on the steady magnetohydrodynamic (MHD) flow over a stretchable surface within a porous channel, considering the impacts of thermal radiation and viscous heating.

Nagarajan *et al.* [50] examined the impact of chemical reactions on an inclined plate, taking into account temperature variations and isothermal mass diffusion.

Bartwal *et al.* [51] analyzed the flow characteristics, including velocity, temperature, skin friction coefficient, and local Nusselt number, under specific conditions when a quadratic convective flow of a tangent hyperbolic fluid is applied over a non-flat stretching sheet. In this scenario, heat transfer is modeled using a modified version of Fourier's law, enhanced with quadratic thermal radiation. The impact of Soret-Dufour effects and anisotropic slip on the MHD (magnetohydrodynamic) flow of a tangent hyperbolic fluid over a rotating disk with variable thickness was examined by Bartwal *et al.* [52]. The study assumed that the fluid flow is driven by the rotating disk, with temperature-dependent thermal conductivity and dynamic viscosity. The Legendre wavelet collocation method (LWCM) was used to obtain the numerical solution of the resulting nonlinear ordinary differential equations. Bartwal *et al.* [53] incorporated the effects of a magnetic field, melting heat transfer, viscous dissipation, and Joule heating in the study. The probable error (PE) was calculated to assess the reliability of the correlation coefficient of the physical parameters. The influence of the presence and absence of the power-law index parameter was illustrated and compared through graphical and tabular representations. Prakash *et al.* [54] analyzed the melting heat transfer and irreversibility in Darcy-Forchheimer flow of Casson fluids influenced by electro-osmosis and magnetohydrodynamics over wedge and cone surfaces, considering thermal radiation, thermal buoyancy, and heat generation/absorption. Using similarity transformations, they formulated a system of nonlinear ordinary differential equations, which were numerically solved using the shooting method and the fourth-order Runge-Kutta approach with MATLAB's bvp4c tool. Gupta *et al.* [55] explored the solution to the unsteady flow problem of hybrid nanofluid over a stretching surface embedded within the porous medium. Their study dealt with the shape factor analysis by considering four shapes: brick, lamina, platelet, and blade. The Legendre wavelet collocation technique is implemented to obtain the solution to the problem. Again Gupta *et al.* [56] analyzed a conventional fluid consisting of a mixture of water (H_2O) and ethylene glycol ($C_2H_6O_2$), with a volume fraction of *8%* for each of the nanoparticles, graphene (GP) and molybdenum disulfide (MoS_2).

Measured origination

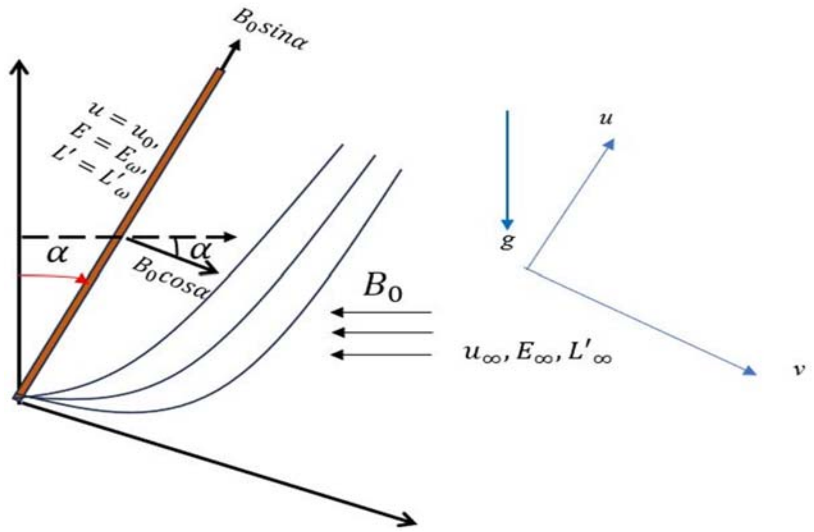

Fig.1. The problem's flow geometry.

The study incorporates the effects of temperature-dependent viscosity (TDV), magnetic field, suction, porosity, and viscous dissipation on temperature, velocity, skin friction, and heat transfer rate. The effects of radiation and Thompson and Trojan boundary slip on the flow of a CNT-Fe_3O_4/kerosene oil (KO) hybrid nanofluid over a porous exponentially stretching sheet was studied by Gupta *et al.* [57]. The viscosity was modeled as temperature-dependent using the Reynolds viscosity model. A comparative analysis was conducted between the SWCNT-Fe_3O_4/KO and MWCNT-Fe_3O_4/KO nanofluids. Nagarajan *et al.* [58] investigated the turbulent flow patterns around an unbounded inclined plate subjected to uniform temperature and varying mass dispersion. The investigation thoroughly examined the effects of chemical reactions within the system, with a particular focus on the harmonic inclination of the plate within its plane.

This study explores hydromagnetic phenomena in flow across an inclined, gradually advancing isothermal surface under heat and mass transfer conditions. To address these challenges, the Laplace-transform (LT) method is employed to solve dimensionless equations, yielding solutions expressed through exponential functions and associated error functions. The findings have broad implications, including control over continuous iron flow in metallurgical processes, fluid conditioning applications, and suppression of molten semiconducting materials, among other potential applications.

2. Formulations of the problem

The unsteady motion of a viscoelastic sixth fluid along a uniformly advancing, inclined, isothermal vertical surface within a magnetic field environment was investigated. This study describes the flow of a viscoelastic fluid, initially at rest, surrounding an infinite vertical surface characterized by E_∞ and L'_∞. The x-axis is assigned vertically upward across the surface, and the y-alignment is assigned vertical to the surface. The surface and liquid are both at E_∞ at $t' \le 0$. The surface is advanced with $u = u_0 t'$ in its possession plane at $t' > 0$, and the temperature is raised to E_ω, as is the intensity value L'_ω near the plate. A consistently robust transverse MF B_0 is presumed to be given perpendicular to the surface. Beneath the normal Boussinesq's estimate, the uneven circulation is then regulated by the underlying formulae:

$$\frac{\partial u}{\partial t'} = g\beta\cos\alpha\left(E - E_\infty\right) + g\beta^*\cos\alpha\left(L' - L'_\infty\right) + \nu\frac{\partial^2 u}{\partial y^2} - \frac{\sigma B_0^2}{\rho}u\,, \tag{2.1}$$

$$\rho L_p \frac{\partial E}{\partial t'} = k\frac{\partial^2 E}{\partial y^2}\,, \tag{2.2}$$

$$\frac{\partial L'}{\partial t'} = D\frac{\partial^2 L'}{\partial y^2}\,. \tag{2.3}$$

The specified initiation and boundary restrictions:

$$\begin{aligned}
&u = 0, \quad E = E_\infty, \quad L' = L'_\infty \quad \text{for all} \quad y, t' \le 0, \\
t' > 0:\ &u = u_0 t', \quad E = E_\omega, \quad L' = L'_\omega \quad \text{at} \quad y = 0, \\
&u \to 0 \quad E \to E_\infty, \quad L' \to L'_\infty \quad \text{as} \quad y \to \infty.
\end{aligned} \tag{2.4}$$

The dimensionless parameters listed below are presented:

$$J=\frac{u}{\left(\nu u_0\right)^{\frac{1}{3}}},\quad t=t'\left(\frac{u_0^2}{\nu}\right)^{\frac{1}{3}},\quad Y=y\left(\frac{u_0}{\nu^2}\right)^{\frac{1}{3}},\quad \theta=\frac{E-E_\infty}{E_\omega-E_\infty},\quad Gr=\frac{g\beta\left(E_\omega-E_\infty\right)}{u_0},$$
$$L=\frac{L'-L'_\infty}{L'_\omega-L'_\infty},\quad Gc=\frac{g\beta^*\left(L'_\omega-L'_\infty\right)}{u_0},\quad M=\frac{\sigma B_0^2}{\rho}\left(\frac{\nu}{u_0^2}\right)^{\frac{1}{3}},\quad \Pr=\frac{\mu L_P}{k},\quad Sc=\frac{\nu}{D}. \tag{2.5}$$

Equations (2.1) to (2.4) results in:

$$\frac{\partial J}{\partial t}=Gr\cos\alpha\,\Omega+Gc\cos\alpha\,L+\frac{\partial^2 J}{\partial Y^2}-MJ, \tag{2.6}$$

$$\frac{\partial\Omega}{\partial t}=\frac{1}{Pr}\frac{\partial^2\Omega}{\partial Y^2}, \tag{2.7}$$

$$\frac{\partial L}{\partial t}=\frac{1}{Sc}\frac{\partial^2 L}{\partial Y^2}. \tag{2.8}$$

Starting as well as limit criteria for the dimensionless values are defined.

$$\begin{array}{llllll} & J=0, & \Omega=0, & L=0 & \text{for all} & Y,\,t\le 0,\\ t>0: & J=t, & \Omega=1, & L=1 & \text{at} & Y=0,\\ & J\to 0, & \Omega\to 0, & L\to 0 & \text{as} & Y\to\infty. \end{array} \tag{2.9}$$

Non - dimensional controlling formulae (2.6) to (2.8) are corrected using the conventional. Laplacian approach and the conceptual answers are given:

$$\Omega=erfc(\lambda\sqrt{\Pr}), \tag{2.10}$$

$$L=erfc(\lambda\sqrt{Sc}). \tag{2.11}$$

Velocity is:

$$\begin{aligned}J=&\left(\frac{t}{2}+c+d\right)\left[e^{2\lambda\sqrt{Mt}}\,erfc\left(\lambda+\sqrt{Mt}\right)+e^{-2\lambda\sqrt{Mt}}\,erfc\left(\lambda-\sqrt{Mt}\right)\right]+\\ &-\frac{\lambda\sqrt{t}}{2\sqrt{M}}\left[e^{-2\lambda\sqrt{Mt}}\,erfc\left(\lambda-\sqrt{Mt}\right)-e^{2\lambda\sqrt{Mt}}\,erfc\left(\lambda+\sqrt{Mt}\right)\right]+\\ &-c\,e^{at}\left[e^{2\lambda\sqrt{A_1}}\,erfc\left(\lambda+\sqrt{A_1}\right)+e^{-2\lambda\sqrt{A_1}}\,erfc\left(\lambda-\sqrt{A_1}\right)\right]+\end{aligned} \tag{2.12}$$

$$-d\,e^{bt}\left[e^{2\lambda\sqrt{A_2}}\,erfc\left(\lambda+\sqrt{A_2}\right)+e^{-2\lambda\sqrt{A_2}}\,erfc\left(\lambda-\sqrt{A_2}\right)\right]-2c\,erfc\left(\lambda\sqrt{\Pr}\right)+$$
$$+c\,e^{at}\left[e^{-2\lambda\sqrt{\Pr at}}\,erfc\left(\lambda\sqrt{\Pr}-\sqrt{at}\right)+e^{2\lambda\sqrt{\Pr at}}\,erfc\left(\lambda\sqrt{\Pr}+\sqrt{at}\right)\right]+ \quad \text{(2.12 cont)}$$
$$-2d\,erfc\left(\lambda\sqrt{Sc}\right)+d\,e^{bt}\left[e^{-2\lambda\sqrt{Sc\,bt}}\,erfc\left(\lambda\sqrt{Sc}-\sqrt{bt}\right)+e^{2\lambda\sqrt{Sc\,bt}}\,erfc\left(\lambda\sqrt{Sc}+\sqrt{bt}\right)\right].$$

where, $a=\dfrac{M}{\Pr-1},\quad b=\dfrac{M}{Sc-1},\quad c=\dfrac{Gr\cos\alpha}{2a(1-\Pr)},\quad d=\dfrac{Gc\cos\alpha}{2b(1-Sc)},$

$A_1=(M+a)t,\quad A_2=(M+b)t$ and $\lambda=Y/2\sqrt{t}$.

Sherwood Number (S_h)

The Sherwood number holds significant importance as a fundamental parameter in the examination of diffusion and mass transfer phenomena. It finds extensive application in various disciplines such as engineering, chemical processes, environmental sciences, and related domains, serving as a valuable tool for the analysis and enhancement of mass transfer phenomena.
S_h is given by:

$$S_h=-\left[\frac{dL}{dy}\right]_{\lambda=0},\quad S_h=\frac{\sqrt{Sc}}{\sqrt{\pi}\sqrt{t}}.$$

Nusselt number (N_u)

The metric in question is a crucial aspect employed in the analysis of heat transfer, specifically to evaluate the efficiency of convective heat transfer and its correlation with conductive heat transfer within fluid-solid systems. Thermal systems optimization and enhancement of energy efficiency are crucial areas of focus in engineering and heat transfer research.
N_u is given by:

$$N_u=-\left[\frac{d\Omega}{dy}\right]_{\lambda=0},\quad N_u=\frac{\sqrt{P_r}}{\sqrt{\pi}\sqrt{t}}.$$

Skin friction (τ)

The skin friction coefficient (C_f) is a dimensionless quantity that quantifies skin friction, which is the resistance experienced by a fluid flow due to the interaction between the fluid and a solid surface. It is defined as the ratio of the wall shear stress (τ) to the dynamic pressure (q) of the fluid flow.
The friction value for dimensionless surfaces seems to be.

$$\tau=-\left[\frac{\partial u}{\partial y}\right]_{y=0}=-\frac{1}{2\sqrt{t}}\left[\frac{du}{d\lambda}\right]_{\lambda=0},$$

$$\begin{aligned}\tau=&\frac{-\sqrt{t}}{4}\left[2\sqrt{M\,t}\left[erfc(\sqrt{M\,t})-erfc(-\sqrt{M\,t})\right]-\frac{4}{\pi}e^{-M\,t}\right]-\frac{1}{4\sqrt{M}}\left[erfc(-\sqrt{M\,t})-\right.\\&\left.+erfc(\sqrt{M\,t})\right]-\frac{c}{2\sqrt{t}}\left[\left(2\sqrt{M\,t}\,erfc(\sqrt{M\,t})-\frac{2}{\sqrt{\pi}}e^{-M\,t}+\frac{4\sqrt{M\,t}}{\sqrt{\pi}}e^{-M\,t}\right)\right]+\\&+\frac{c\,e^{a\,t}}{2\sqrt{t}}\left[2\sqrt{A_1}\left(erfc(\sqrt{A_1})-erfc(-\sqrt{A_1})\right)-\frac{2}{\sqrt{\pi}}e^{-A_1}\right]-\frac{d}{2\sqrt{t}}\left[\left(2\sqrt{M\,t}\,erfc(\sqrt{M\,t})-\right.\right.\\&\left.\left.+\frac{2}{\sqrt{\pi}}e^{-M\,t}+\frac{4\sqrt{M\,t}}{\sqrt{\pi}}e^{-M\,t}\right)\right]+\frac{d\,e^{bt}}{2\sqrt{t}}\left[2\sqrt{A_2}(erfc(\sqrt{A_2})-erfc(-\sqrt{A_2}))-\frac{2}{\sqrt{\pi}}e^{-A_2}\right]+\\&-\frac{2c}{\sqrt{t\,M}}-\frac{c\,e^{at}}{2\sqrt{t}}\left[2\sqrt{\Pr a\,t}(erfc(\sqrt{a\,t})-erfc(-\sqrt{a\,t}))-\frac{4}{\sqrt{\pi}}e^{-a\,t}\right]+\\&-\frac{2d}{\sqrt{t\,M}}-\frac{d\,e^{bt}}{2\sqrt{t}}\left[2\sqrt{Sc\,b\,t}(erfc(\sqrt{b\,t})-erfc(-\sqrt{b\,t}))-\frac{4}{\sqrt{\pi}}e^{-b\,t}\right]\end{aligned}\tag{2.13}$$

where, $A_1=(M+a)t$, $A_2=(M+b)t$.

Table 1. Skin-friction for varying factors.

α (angle)	t	Sc	Pr	Gr	Gc	M	τ
$\pi/6$	0.2	2.01	7	5	5	5	-4.5236
$\pi/4$	0.4	2.01	7	2	2	5	-5.4136
$\pi/3$	0.6	2.01	7	5	2	10	-0.4953
$\pi/6$	0.4	2.01	7	2	2	2	0.2939
$\pi/4$	0.2	2.01	7	5	2	5	-0.8933
$\pi/3$	0.8	2.01	7	2	5	2	-6.9678
$\pi/6$	0.6	2.01	7	2	5	5	-28.7718
$\pi/4$	0.8	2.01	7	5	5	2	-11.2327
$\pi/3$	0.2	2.01	7	2	2	5	0.2646

Table 2. Sherwood quantity for various factors.

t	Sc	Sh
0.2	0.16	0.5046
0.2	0.6	0.9772
0.4	0.16	0.3568
0.4	0.6	0.6909
0.2	0.3	0.6909
0.2	2.01	1.7885
0.4	0.3	0.4886
0.4	2.01	1.2647

Table 3. The Nusselt amount for different parameters.

t	Pr	Nu
0.2	0.71	1.0630
0.2	7.0	3.3379
0.4	0.71	0.7517
0.4	7.0	2.3604
0.6	0.71	0.6132
0.6	7.0	1.9254

3. Numerical approach

The initial step involves using the finite difference discretization scheme to discretize the nonlinear Eqs (2.6)-(2.8). The central difference approximations are employed for solving the spatial derivatives, while the explicit forward finite difference approximations are utilized for subsequently discretizing the temporal derivative.

$$J=\frac{1}{2}\left[\frac{u_i^{n+1}-u_i^n}{\Delta t}\right],\quad \Omega=\frac{1}{2}\left[\frac{\theta_i^{n+1}-\theta_i^n}{\Delta t}\right],\quad L=\frac{1}{2}\left[\frac{\sigma_i^{n+1}-\sigma_i^n}{\Delta t}\right], \tag{3.1}$$

$$\begin{gathered}\left[\frac{J_i^{n+1}-J_i^n}{\Delta t}\right]=\left[\frac{\left(J_{i+1}^{n+1}-2J_i^{n+1}+J_{i-1}^{n+1}\right)+\left(J_{i+1}^n-2J_i^n+J_{i-1}^n\right)}{2(\Delta y)^2}\right]+ \\ +Gr\cos\alpha\left[\frac{\Omega_i^{n+1}+\Omega_i^n}{2}\right]-M\left[\frac{J_i^{n+1}+J_i^n}{2}\right]+Gc\cos\alpha\left[\frac{L_i^{n+1}+L_i^n}{2}\right],\end{gathered} \tag{3.2}$$

$$\left[\frac{\Omega_i^{n+1}-\Omega_i^n}{\Delta t}\right]=\frac{1}{\Pr}\left[\frac{\left(\Omega_{i+1}^{n+1}-2\Omega_i^{n+1}+\Omega_{i-1}^{n+1}\right)+\left(\Omega_{i+1}^n-2\Omega_i^n+\Omega_{i-1}^n\right)}{2(\Delta y)^2}\right], \tag{3.3}$$

$$\left[\frac{L_i^{n+1}-L_i^n}{\Delta t}\right]=\frac{1}{Sc}\left[\frac{\left(L_{i+1}^{n+1}-2L_i^{n+1}+L_{i-1}^{n+1}\right)+\left(L_{i+1}^n-2L_i^n+L_{i-1}^n\right)}{2(\Delta y)^2}\right]. \tag{3.4}$$

4. Results and discussion

Mathematical computations for numerous physical variables are done to get a fundamental insight of the condition which includes all the significant parameters. $Sc=2.01$ relates to water vapor. Various physical characteristics such as Gr, Gc, Sc, Pr, M, t, v, T, and intensity are estimated.

Velocity, temperature, and concentration profile

The nondimensional velocity, temperature, and concentration profiles for different assumptions of physical parameters are depicted in Figs 2-7. Figure 2 shows the influence of various values of $M=1, 3, 5$ and $t=0.2$, $Pr=7$, $Gr=Gc=5$. It was determined that reducing the magnetic field component improved the degree of tilt. As a result of the magnetic environment acting as a restricting influence on the unconstrained convection, raising the magnetic field variable induces a drop in velocity. It was discovered that the magnetic field parameter increases with decreasing angles. This demonstrates that augmenting the magnetic field parameter leads to a reduction in velocity because the magnetic environment retards the free convective flow.

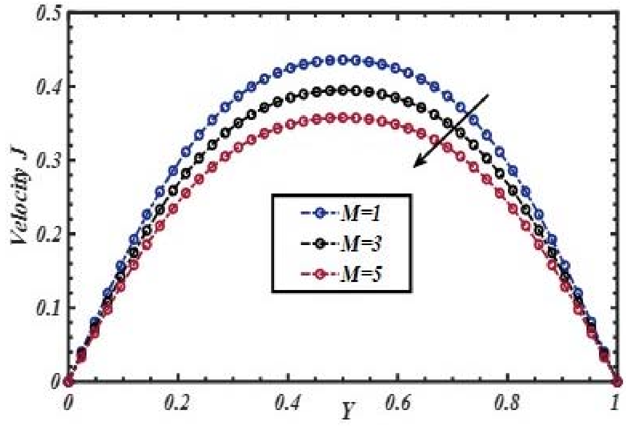

Fig.2. Velocity profile vs *M*.

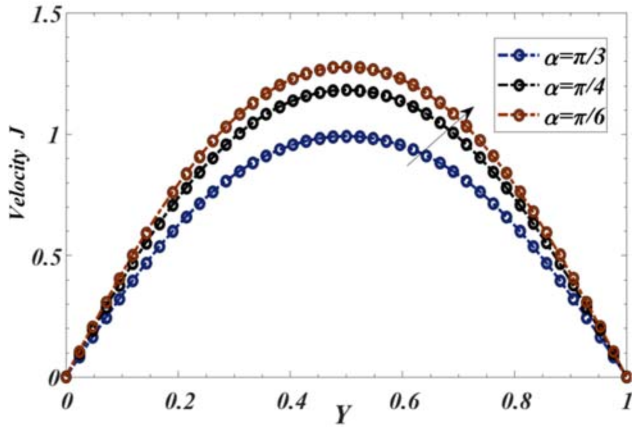

Fig.3.Velocity profile vs inclined angle (α).

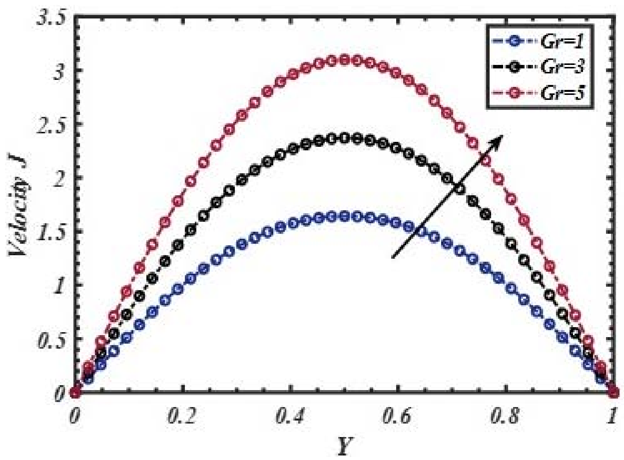

Fig.4. Velocity profile vs *Gr*.

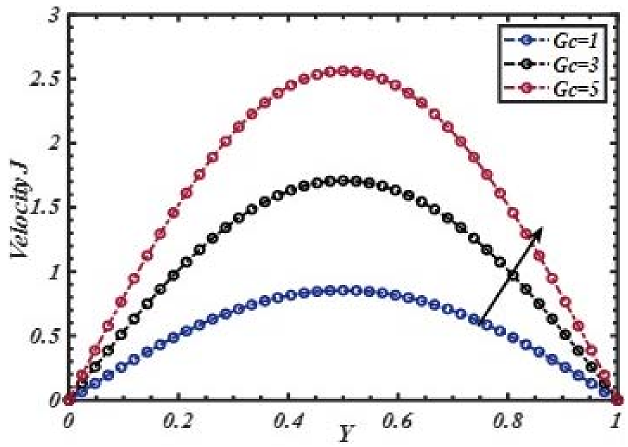

Fig.5. Velocity profile vs *Gc*.

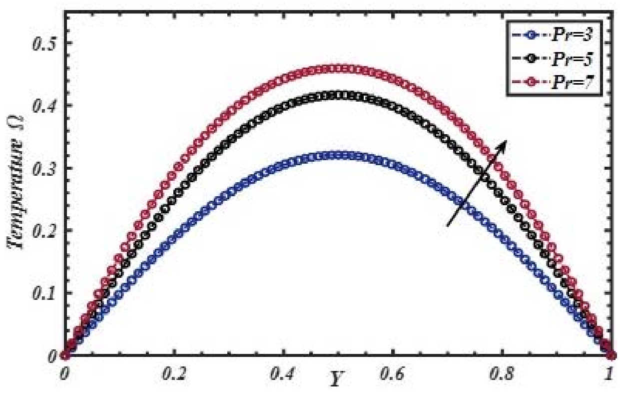

Fig.6. Temperature profile vs *Pr*.

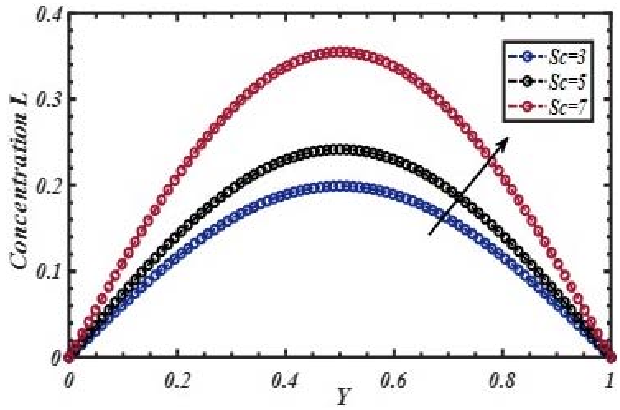

Fig.7. Concentration profile vs *Sc*.

The velocity profiles for different angles ($\alpha = \pi/6,\ \pi/4,\ \pi/3,\ Gr = 2$ and $Gc = 5$, $M = 2$, $P_r = 7,\ Sc = 2.01$ are investigated and presented in Fig.3. It is discovered that as the angle of attack augments, so does the velocity which enhances with the α values. Figure 4 depicts the influences of various Gr. $Gr = 2, 5, 10, 15$, time at 0.2, $\Pr = 7, Sc = 2.01, Gc = 5, M = 2$ and angle fixed at $\pi/3$. Here also, Gr is directly proportional to velocity. Figure 5 depicts the effects of various mass grashof number $(Gc = 1, 3, 5)$, $t = 0.6$, $Pr = 7, Sc = 2.01, Gr = M = 2$, and angle $\pi/4$. Moreover, the variable *Gc* exhibits a direct proportionality with the velocity profile. Figure 6 illustrates the effects of different parameters, specifically Prandtl number $(Pr = 3,\ 5,\ 7)$, angle of inclination (α), and $M = 2$, angle $\pi/3$ on the velocity, which exhibits a proportionate increase with *Tm* and *Tg*. Figure 7 illustrates the influence of the Schmidt number (*Sc*) on the concentration distribution at a designated time point $(t = 0.4)$ for several *Sc* values, specifically *3*, *5*, and *7*. The findings suggest that an increase in the Schmidt number (*Sc*) is associated with a concomitant elevation in the concentration profile.

Table 1 reveals the impact of LSF on many parameters, encompassing Prandtl number, Schmidt number, magnetic effects, thermal Grashof number, mass Grashof number, and inclination angles. The augmentation in casing resistance is influenced by the Prandtl and Schmidt values, as well as the parameter α. But it has a contradictory impact, growing Grashof numbers for time, temperature, and mass.

Table 2 presents the impact of the physical variables *Sc* and *t* on the variable *Sr*. The rise of *Sh* is accompanied by the rise of *Sc*. As the magnitude of transmission increases, the *Sc* also exhibits an upward trend. Table 3 presents the Nusselt numbers (*Nu*) corresponding to different physical factors and time intervals. An increase in the Prandtl number results in a corresponding increase in the Nusselt number. Given the aforementioned circumstances, it may be argued that there is an observed increase in heat transport, coinciding with a corresponding elevation in the Prandtl number.

5. Conclusions

The movement through a consistently advanced limitless isothermal tilted surface with changing mass diffusion has been thoroughly analyzed. The conventional finite difference approach is employed to resolve the dimensionless regulating formulae.

- The impacts of *Tg*, *Tm* well as magnetic environment influences are depicted. The velocity increases proportionally with Gr, Gc. But, the tendency is inverted in terms of the magnetic field variable.
- The confined covering resistance rises when angle (α), *Pr*, *Sc* elevates and reduces during the augmentation of *Gr*, *Gct*.
- The Prandtl and Schmidt values, as well as α, all contribute to an augmentation in casing resistance. But it has a contradictory impact, growing Grashof numbers for time, temperature, and mass.
- The magnetic field parameter leads to a reduction in velocity because the magnetic environment retards the free convective flow.

NOMENCLATURE

A – constant

B_0 – external magnetic field

D – mass diffusion coefficient

E, E' – temperature of the fluid near the plate

E_ω – temperature of the plate

E'_ω – temperature on the wall

E_∞ – temperature of the fluid far away from the plate

$erfc$ – complementary error function
Gc – mass Grashof number
Gr – thermal Grashof number
g – accelerated due to gravity
J – dimensionless velocity
k – thermal conductivity
L – dimensionless concentration
L' – species concentration in the fluid
L_p – specific heat at constant pressure
L'_ω – concentration of the plate
L'_∞ – concentration of the fluid far away from the plate
M – magnetic field parameter
Nu – Nusselt number
Pr – Prandtl number
Sc – Schmidt number
Sh – Sherwood number
t – dimensionless time
t' – time
u – velocity of the fluid in the x-direction
u_0 – velocity of the plate
x – spatial coordinate along the plate
Y – dimensionless coordinate axis normal to the plate
y – coordinate axis normal to the plate

Greek symbols

α – angle of inclination
β – volumetric coefficient of thermal expansion
β^* – volumetric coefficient of expansion with concentration
λ – similarity parameter
μ – cofficient of viscosity
υ – kinematic viscosity
ρ – density of the fluid
σ – electric conductivity
τ – dimensionless skin-friction
Ω – dimensionless temperature

Subscripts

ω – conditions at the wall
∞ – conditions in the free stream

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