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Research Article

MHD stream past an inclined surface with diffusion-thermo and viscous dissipation sequels

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ABSTRACT

The steady-state MHD (Magnetohydrodynamics) incompressible free convective boundary layer stream over an inclined surface, moving continuously in the existence of heat along with mass transfer is studied. The interpretation of Diffusion-thermo, Viscous dissipation, and Thermophoresis has been emphasized. To decompose the heat and mass transport, a two-dimensional steady flow model formed by appurtenant boundary conditions is created. The equations that govern the system are solved using numerical techniques, specifically the bvp4c solver in MATLAB, with appropriate boundary conditions. Numerical constellations are also plotted to validate the results and the acquired relevant parameters are effectively analysed. This incorporation expands on prior investigations and enhances our comprehension of these intricate interrelations. Adequate validation has been performed against previously published articles and positive agreement has been observed. The Nusselt number and temperature profile decrease with increasing Dufour number, while a noticeable change in behaviour is observed in the concentration profile and Sherwood number. The research is significant as it provides insights into improving heat and mass transfer mechanisms, which are essential in a variety of engineering challenges, including Chemical Industries, Nuclear Reactors, and Metallurgical Industries. The findings from the study of MHD flow through inclined surfaces with diffusion-thermo and viscous dissipation effects have broad applicability and implications in various engineering fields. This research has the potential to significantly impact process optimization, control flow patterns in metallurgical furnaces, enhance heat transfer, and improve energy efficiency. It also contributes to the design and analysis of liquid metal-cooled nuclear reactors.

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INTRODUCTION

Considering boundary layer streams persistently in motion surfaces, numerous viable applications have been noticed in industrial and mechanical forms. A few illustrations of continuously moving surfaces are streamlined expulsion of plastic sheets; freezing interminable metal plate in a cooling way (possibly an electrolyte); precious stone developing; boundary layer besides a fluid film

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during condensation; tempered fabric moving between a bolster roll and completed roll. The appraisals of Sakiadis [1], Erickson *et al.* [2], Ishak *et al.* [3], Fang [4], Afzal *et al.* [5], Takhar *et al.* [6], etc. are praiseworthy in case of boundary layer stream on a ceaseless moving surface.

In numerous sciences and design themes, the motion of synchronous heat and mass interchange is employed. Convection streams combined with heat and mass transmission have numerous usages inside several fields concerning science and technology. It is utilized in food handling, thermometer (wet bulb), polymer arrangement and many other fluids flow problems. We observe the circumstance of combined heat and mass exchange during fog formation in our everyday life. In the studies conducted by Makinde [7], Chen [8], Ali et al. [9], Alam et al. [10], Reddy and Reddy [11], Makinde and Aziz [12], Bhatti et al. [13], and Beg et al. [14], different flow conditions for various fluid flow models have been investigated. These studies have considered the impact of factors such as porosity, inclination, and MHD (Magnetohydrodynamics), which is the study of the behaviour of electrically conducting fluids under the influence of a magnetic field. MHD has applications in diverse fields including plasma physics, astrophysics, and the development of MHD generators and pumps.

Heat transport through concentration gradients and thermal energy transfer through temperature gradients are of incredible importance and have been examined by a number of researchers. The synchronous heat and mass exchange in moving fluid complicates the affinity linking fluxes and forced possibilities. "The energy flow is induced by temperature gradients as well as by compositional gradients and this energy flow generated by compositional gradient is called the Diffusion-thermo or Dufour effect". Basically, "the Dufour impacts are of a smaller arrangement of magnitude than the impacts depicted by Fourier's or Fick's law and it has been found to be of impressive size in a mixture between gases with exceptional light atomic weight (H_2, He) and of medium atomic weight (N_2, air) in such a way that it cannot be overlooked" (Eckert and Drake [15]). Considering the importance of the above effects, the mathematical study of this sort of problem has been broadly examined talked about by a few authors such as Postelnicu [16], Anghel *et al.* [17], Mopuri *et al.* [18], Qureshi *et al.* [19], Hayat *et al.* [20],, Alam *et al.* [21], Subba Reddy *et al.* [22], Pal and Mandal [23] etc.

The exploration of the thermophoretic deposition of small particles (such as dust and aerosols) within the nearness of expansive temperature gradients have picked up significance in numerous engineering uses in recent decades. Thermophoresis has many technical applications, such as evacuating little particles from gas pours, in deciding to deplete gas molecule directions from combustion gadgets and in considering the particulate fabric statement on turbine edges. With regard to different application of thermophoresis, Selim *et al.* [24] used thermophoresis to examine the impact of surface mass exchange on a mixed convection stream through a flat and porous plate. The impacts of thermophoresis molecule testimony in natural convection stream from a flat vertical plate inserted in a permeable medium is explored by Chamkha and Pop [25]. Later El-Kabeir *et al.* [26], Alam *et al.* [27], Kabir and Al Mahbub [28] and Alam [29] conducted studies that considered thermophoresis and other effects.

Viscous dissipation is an irreversible process in which work done by fluids in adjoining layers is converted to heat under the activity of shear forces. Viscous dissipation is of intrigue for numerous application: critical heat is perceived in polymer handling streams such as infusion molding or high-speed extrusion. Streamlined warming within the thin boundary layer throughout fast moving airships increases skin temperature. The viscous dissipation for liquids containing suspended particles is likened to viscous dissemination in an immaculate Newtonian fluid, both of which are in the same stream system. In recent years, various analysts like Alam *et al.* [30], Reddy [31, 32], Raju *et al.* [33], Palani and Arutchelvi [34], Umavathi *et al.* [35] have paid a great deal of attention to the study of issues related to viscous dissipation.

From an application point of view, analysts have talked about the fluid stream through an inclined surface and a few pertinent studies are listed such as Kierkus [36], Umemura and Law [37], Pop *et al.* [38], Chamkha *et al.* [39], Ramesh *et al.* [40], Sudarmozhi *et al.* [41].

This interrogation explores the combined impacts of Diffusion-thermo, Viscous dissipation on the steady-state MHD (Magnetohydrodynamics) free convective heat and mass exchange stream of viscous fluids passing through an inclined penetrable moving surface in the companionship of Thermophoresis. The researchers used various analytical/numerical methods in the above studies. Therefore, an attempt is made to investigate this problem using MATLAB›s built-in solver bvp4c. The study offers insights into how industrial heat exchangers can optimize heat transfer by considering the significant role of MHD effects. Understanding diffusion-thermo and viscous dissipation is crucial for improving processes related to the cooling and solidification of materials in manufacturing. The findings may also help in designing systems to control heat and mass transfer in environmental engineering. The research highlights the importance of understanding MHD flows in various engineering contexts and their relevance to contemporary challenges in thermal management and fluid dynamics.

FORMULATION OF THE PROBLEM

This segment presents a diagrammatic arrangement of the considered problem in Figure 1. Here, we try to understand two-dimensional boundary layer free relentless convection fluid flow on a persistently moving inclined surface, which is emerged from an opening and operating throughout the fluid with steady speed U.

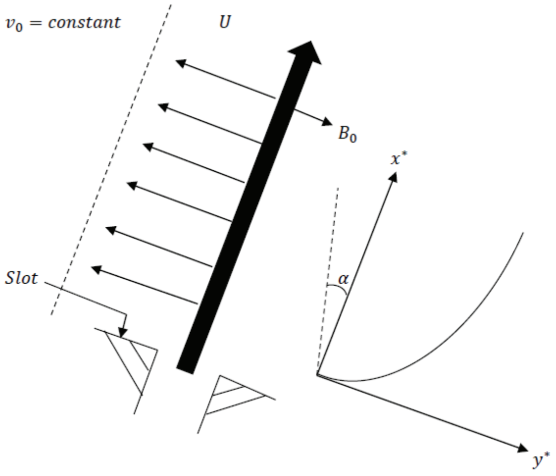

Figure 1. Physical model of the problem.

Here the steady-state behavior of the system is considered as steady-state problems converge faster in numerical simulations and its solutions are more balanced and less prone to numerical instability than unsteady solutions. The surface is accepted to be permeable such that a conceivable suction effect happens at the surface and heat is provided to the surface at a steady rate. The surface makes a very small angle α to the vertical so that $\sin\alpha = 0$. The x^*- axis extends alongside the surface where the y^*- axis perpendicular to this. A varying magnetic field of intensity B_0 is applied normally to the surface and aligned to the y^*- axiss.

Subject to the over presumptions, the commanding equations are approximated to $\frac{\partial v^*}{\partial y^*} = 0$

$$\therefore\ v^* = -v_0 \ \text{(Where } v_0 > 0 \text{ is a constant)} \tag{1}$$

$$v^* \frac{\partial u^*}{\partial y^*} = \nu \frac{\partial^2 u^*}{\partial y^{*2}} + g\beta \cos\alpha\,(T - T_\infty) + g\beta^* \cos\alpha\,(C - C_\infty) - \frac{\sigma B_0^2 u^*}{\rho} - \frac{\nu u^*}{K_p} \tag{2}$$

$$v^* \frac{\partial T}{\partial y^*} = \frac{\kappa}{\rho C_p}\frac{\partial^2 T}{\partial y^{*2}} + \frac{\nu}{C_p}\left(\frac{\partial u^*}{\partial y^*}\right)^2 + \frac{D_m \kappa_T}{C_s C_p}\frac{\partial^2 C}{\partial y^{*2}} \tag{3}$$

$$v^* \frac{\partial C}{\partial y^*} = D\frac{\partial^2 C}{\partial y^{*2}} - \frac{\partial}{\partial y^*}[V_T(C - C_\infty)] \tag{4}$$

The physical problem proposes the following prior condition:

$$\begin{aligned} &y^* = 0: && u^* = U, && \frac{\partial T}{\partial y^*} = -\frac{q}{\kappa}, && C = C_w. \\ &y^* \to \infty: && u^* \to 0, && T \to T_\infty, && C \to C_\infty. \end{aligned} \tag{5}$$

The following non-dimensional quantities are instituted as:

$$\begin{aligned} &u = \frac{u^*}{U},\ y = \frac{y^* v_0}{\nu},\ \theta = \frac{T - T_\infty}{q\nu/\kappa v_0},\ \phi = \frac{C - C_\infty}{C_w - C_\infty},\ M = \frac{\sigma B_0^2 \nu}{\rho v_0^2}, \\ &Gr = \frac{\nu g\beta(q\nu/\kappa v_0)}{U v_0^2},\ Gm = \frac{\nu g\beta^*(C_w - C_\infty)}{U v_0^2},\ Pr = \frac{\rho \nu C_p}{\kappa}, \\ &Sc = \frac{\nu}{D},\ E = \frac{U^2 \kappa v_0}{q \nu C_p},\ \frac{q}{\kappa} = \frac{v_0}{\nu}(T_w - T_\infty),\ K = \frac{K_p v_0^2}{\nu^2}, \\ &V_T = -\frac{\nu K_T}{T_r}\frac{\partial T}{\partial y^*},\ \delta = -\frac{K_T(q\nu/\kappa v_0)}{T_r}. \end{aligned} \tag{6}$$

With the above changes, the initial commanding equations (2) to (4) are changed to the following arrangement:

$$u'' + u' - \left(M + \frac{1}{K}\right)u = -Gr\theta\cos\alpha - Gm\phi\cos\alpha \tag{7}$$

$$\theta'' + Pr\theta' = -PrE(u')^2 + DuPr\phi'' \tag{8}$$

$$\phi'' + Sc\phi' = Sc\delta(\phi\theta'' + \phi'\theta') \tag{9}$$

The corresponding limiting conditions are changed into:

$$\begin{aligned} &y = 0: && u = 1, && \theta' = -1, && \phi = 1. \\ &y \to \infty: && u \to 0, && \theta \to 0, && \phi \to 0. \end{aligned} \tag{10}$$

Method of Solution

The set of commanding equations (2) to (4) under relevant limiting conditions (5) is converted to an appropriate format by proper transformations (6) and the new set of equations (7) to (9) in conjunction with transformed conditions (10) is approximated by numerical program of bvp4c in MATLAB interface. The bvp4c program is one of the latest additions to MATLAB's built-in boundary value problem solvers which handle ordinary linear equations and this solver was advanced by Kierzenka and Shampine [42]. The course of action obtained for fluid transportability, distribution of heat, dispersion of mass has been portrayed in a pictorial perspective and quantitative data relating to the "Coefficient of Skin Friction", "Nusselt Number", and "Sherwood Number" are confirmed through tables in conceivable cases.

RESULTS AND DISCUSSION

Considering the top grey literature and current probe, the resourcefulness of the customary problem is to study the upshots of dynamic variables on the properties of fluid across the inclined surface where Diffusion-thermo effect and Viscous dissipation are present. Moreover, the physical problem considered have strong nonlinearities and coupling flow equations and these transformed ordinary differential equations underlying boundary conditions computed using bvp4c solver. We demonstrate the impacts of "pertinent parameters on fluid Velocity, fluid Temperature, species Concentration, Skin friction, Nusselt number and

Sherwood number" by allotting values as $M = 2$, $K = 0.1$, $Gr = 7$, $Gm = 10$, $\alpha = \pi/4$, Pr =6.9, $E = 0.001$, $Sc = 0.5$, $\delta = 1.5$, $Du = 0.15$ within the complete investigation if not mentioned, while the impacts of the aforesaid parameters are altogether examined and are shown in tabular and graphical perspective.

Figures 2 to 7 outline the velocity dispersion distinctive flow parameters related to fluid movement.

In Figure 2, we can see the significant impact of the magnetic field. It has been found that as the magnetic parameter increases, the momentum boundary layer experiences a significant decrease, leading to the reverse constraint on the flow known as the Lorentz force. As a result, the fluid velocity decreases.

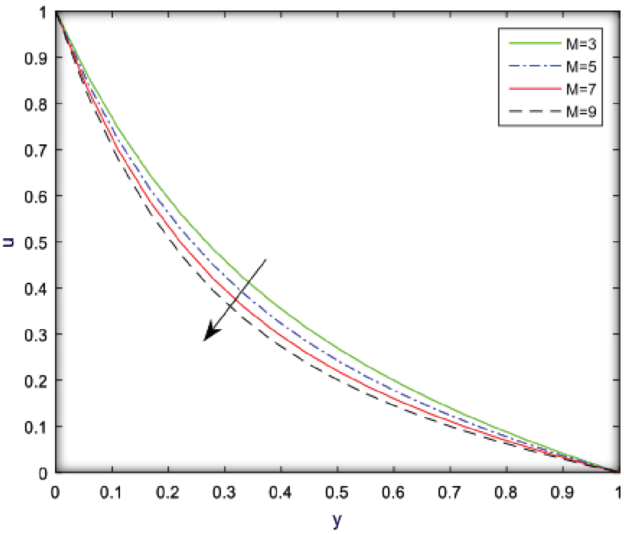

Figure 2. Impact of M on the velocity profile for $K = 0.1$, $Gr = 7$, $Gm = 10$, $\alpha = \pi/4$, $Pr = 6.9$, $E = 0.001$, $Sc = 0.5$, $\delta = 1.5$, $Du = 0.15$.

The velocity patterns represent the ramifications of the thermophoresis parameter and inclination angle are displayed in (Fig. 3, 4) respectively. As the thermophoresis parameter (δ) increases, it enhances the thermophoretic force on the fluid particles. This force opposes the fluid motion, leading to a reduction in the velocity distribution within the boundary layer (Fig. 3). Furthermore, the velocity field is governed by the change in inclination angle(α) (Fig. 4). Barring the extraordinary values of the point of inclination ($0 < \alpha < \pi/2$), we find that a growth of inclination reduces the fluid velocity. This is because as the angle of inclination increases, the flow path along the surface extends, leading to increased viscous drag and consequent reduction in the velocity profile.

Figure 5 displays the velocity distribution for various solutal Grashof number (Gm). The solutal Grashof number measures the balance between species buoyancy and viscous hydrodynamic forces. As the species buoyancy force increases, the fluid velocity accelerates, and the peak value becomes more prominent. This means that the species buoyancy force intensifies the fluid movement.

Figures 6, 7 show the ascendancy of permeability parameter and Eckert number on fluid mobility respectively. The velocity of the fluid rises (Fig. 6) as the permeability parameter (K) increases, since the media is porous and provides more room for the fluid to move. Also, Figure 7 shows that the fluid velocity increases as the Eckert number (E) rises. Viscous dissipation generates more heat, which in turn increases the resistance between this additional heat and

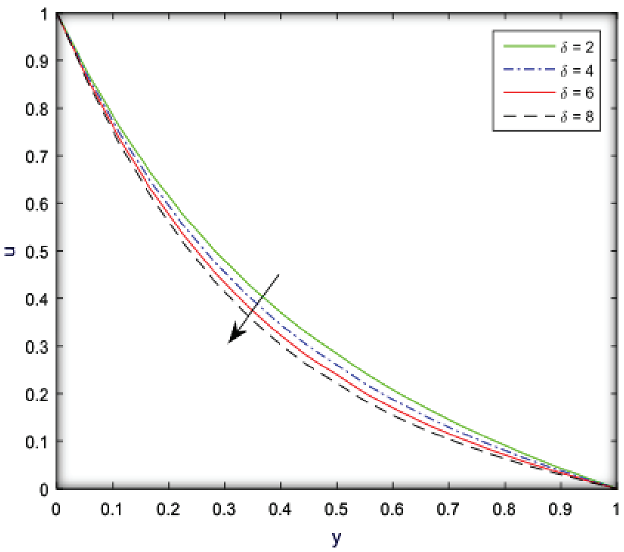

Figure 3. Influence of δ on the velocity profile when $K = 0.1$, $Gr = 7$, $Gm = 10$, $\alpha = \pi/4$, $Pr = 6.9$, $E = 0.001$, $Sc = 0.5$, $M = 2$, $Du = 0.15$.

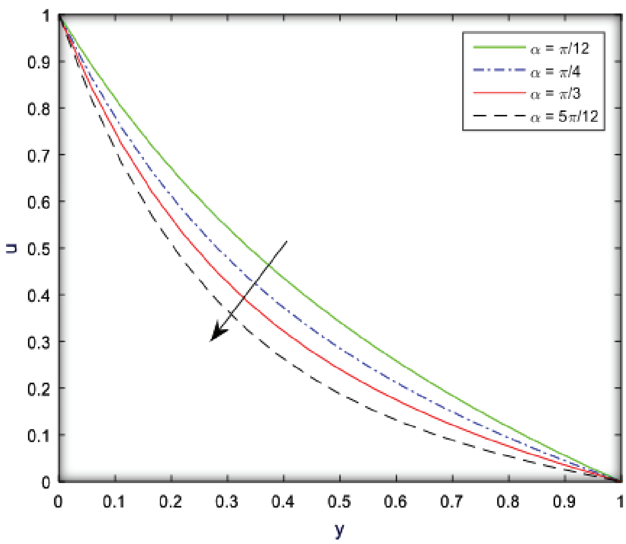

Figure 4. Impression of α on the velocity profile for $K = 0.1$, $Gr = 7$, $Gm = 10$, $\delta = 1.5$, $Pr = 6.9$, $E = 0.001$, $Sc = 0.5$, $M = 2$, $Du = 0.15$.

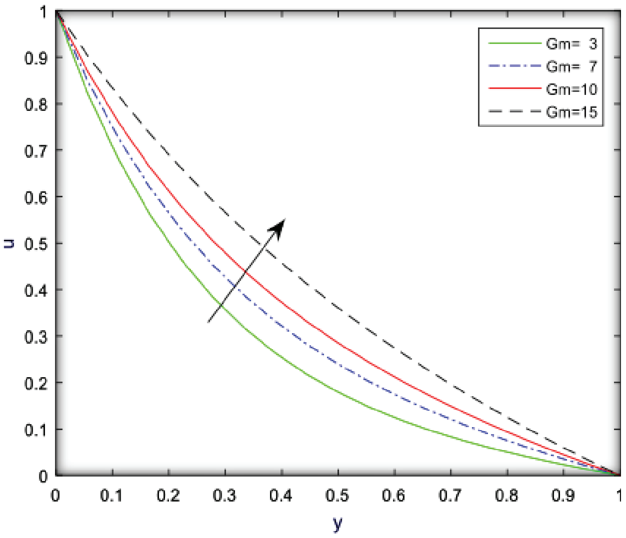

Figure 5. Upshot of Gm on the velocity profile when $K = 0.1$, $Gr = 7$, $\alpha = \pi/4$, $\delta = 1.5$, $Pr = 6.9$, $E = 0.001$, $Sc = 0.5$, $M = 2$, $Du = 0.15$.

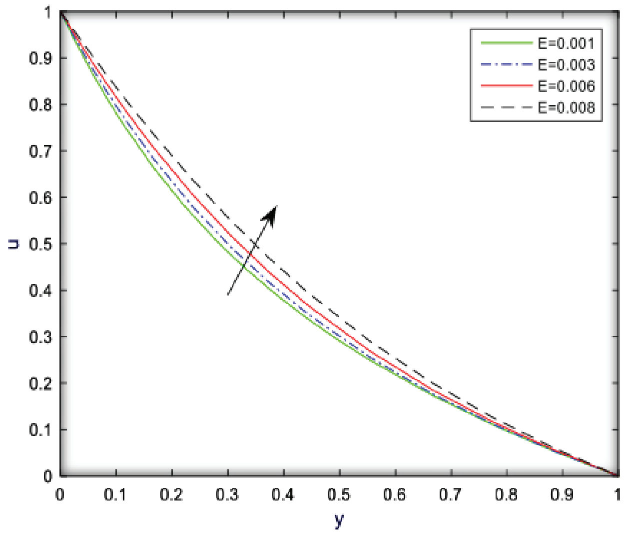

Figure 7. Influence of E on the velocity profile for $Gm = 10$, $Gr = 7$, $\alpha = \pi/4$, $\delta = 1.5$, $Pr = 6.9$, $K = 0.1$, $Sc = 0.5$, $M = 2$, $Du = 0.15$.

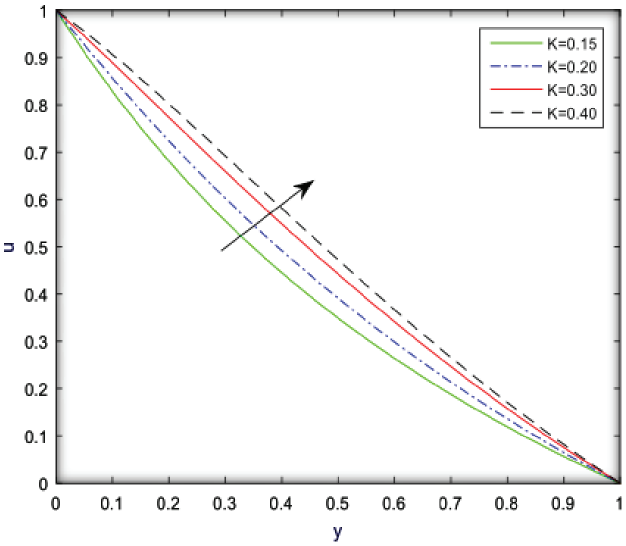

Figure 6. Disparity of K on the velocity profile when $Gm = 10$, $Gr = 7$, $\alpha = \pi/4$, $\delta = 1.5$, $Pr = 6.9$, $E = 0.001$, $Sc = 0.5$, $M = 2$, $Du = 0.15$.

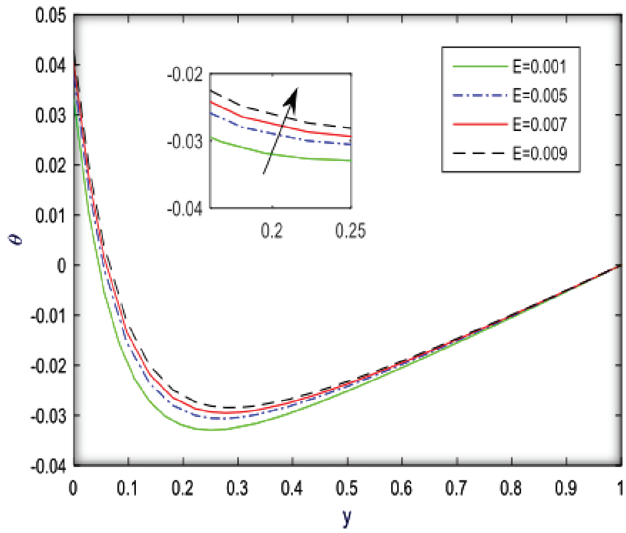

Figure 8. Variation of E on the temperature profile when $Gm = 10$, $Gr = 7$, $\alpha = \pi/4$, $\delta = 1.5$, $Pr = 6.9$, $K = 0.1$, $Sc = 0.5$, $M = 2$, $Du = 0.15$.

the fluid nanoparticles, leading to a rise in the fluid temperature and an expansion of the momentum boundary layer.

The influence of associated parameters on heat distribution of flow has been represented at Figures 8 to 11.

In Figure 8, the impact of the Eckert number (E) on the temperature field is evident. As the Eckert number increases, the thermal boundary layer thickness also increases. This is due to the growing significance of energy dissipation as temperature allocation progresses.

The Figures 9, 10 depict the influence of the Schmidt number and Dufour effect on the temperature profile. As the Schmidt number (Sc) increases (Fig. 9), the temperature profile decreases. The impact of the Dufour effect on temperature distribution is outlined in Figure 10, showing that temperature decreases with higher values of Du. It is interpreted that a greater concentration difference plays a role in reducing fluid temperature near the surface.

The changes in the temperature field for various Prandtl number (Pr) values are shown in Figure 11. As the Prandtl

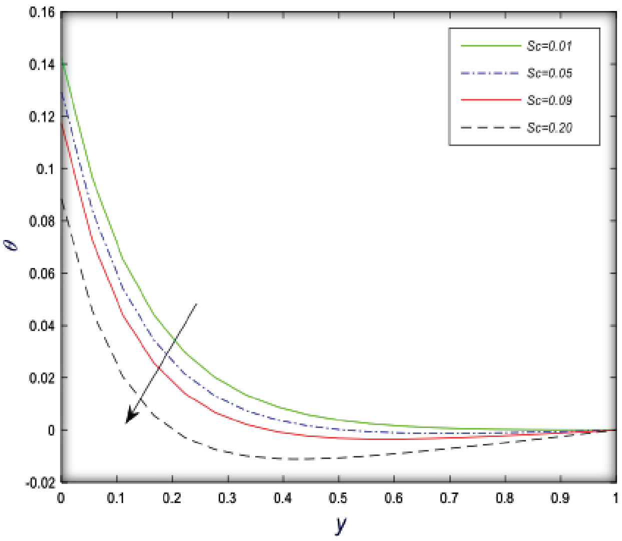

Figure 9. Consequence of Sc on the temperature profile for $Gm = 10$, $Gr = 7$, $\alpha = \pi/4$, $\delta = 1.5$, $Pr = 6.9$, $K = 0.1$, $E = 0.001$, $M = 2$, $Du = 0.15$.

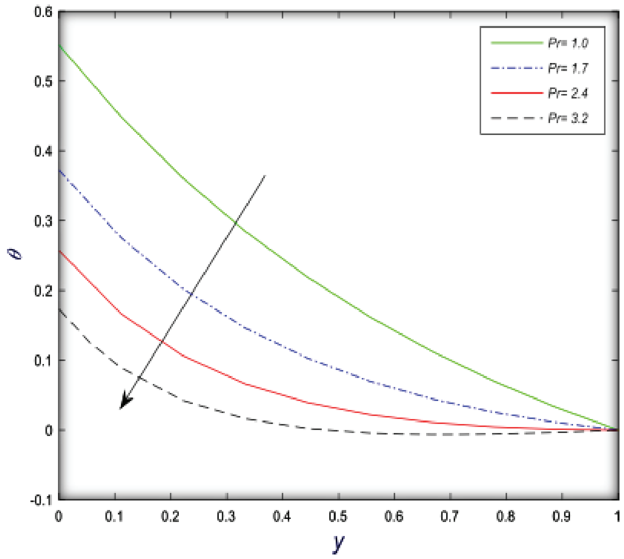

Figure 11. Repercussions of Pr on the temperature profile when $Gm = 10$, $Gr = 7$, $\alpha = \pi/4$, $\delta = 1.5$, $Sc = 0.5$, $K = 0.1$, $E = 0.001$, $M = 2$, $Du = 0.15$.

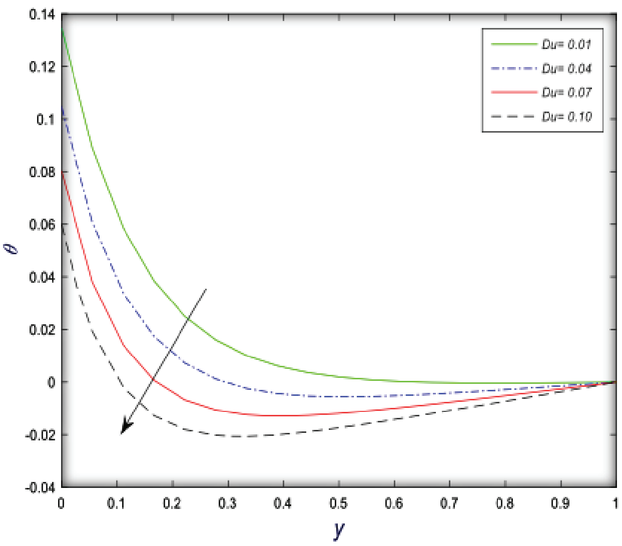

Figure 10. Ramification of Du on the temperature profile when $Gm = 10$, $Gr = 7$, $\alpha = \pi/4$, $\delta = 1.5$, $Pr = 6.9$, $K = 0.1$, $E = 0.001$, $M = 2$, $Sc = 0.5$.

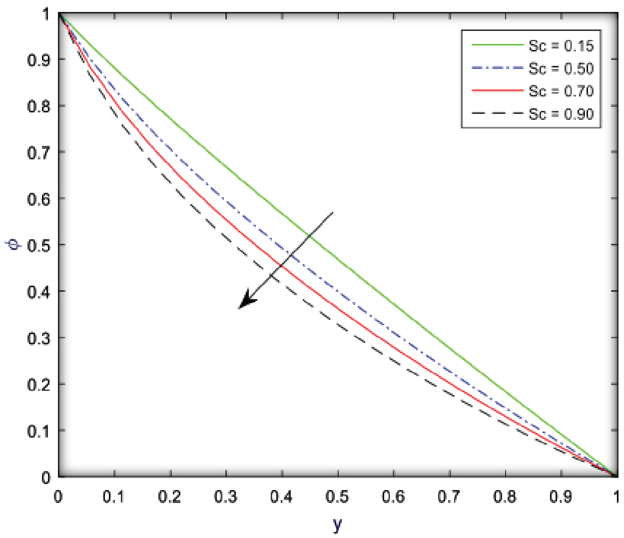

Figure 12. Inconsistency of Sc on the concentration profile for $Gm = 10$, $Gr = 7$, $\alpha = \pi/4$, $\delta = 1.5$, $Pr = 6.9$, $K = 0.1$, $E = 0.001$, $M = 2$, $Du = 0.15$.

number increases, we can observe a damping effect on the fluid temperature. This is because as the Prandtl number increases, the thermal diffusivity decreases relative to the momentum diffusivity of the fluid, resulting in a decrease in temperature.

The portrayal of variances within the concentration profile has been displayed in Figures 12 to 15.

An increase in the Schmidt number (Sc) seems to have a stabilizing effect on the concentration profile, as shown in Figure 12. As the Schmidt number increases, there is a noticeable decrease in the mass transfer profile. In physical terms, higher Schmidt numbers indicate lower molecular dispersion. Consequently, the transport of mass increases with lower Schmidt numbers and decreases as the Schmidt number increases.

Figure 13 illustrates the variation of the concentration profile for different values of the Dufour effect. It is evident from the figure that higher values of Du correspond to an increased concentration profile. This can be attributed to the fact that higher Du values indicate a more substantial

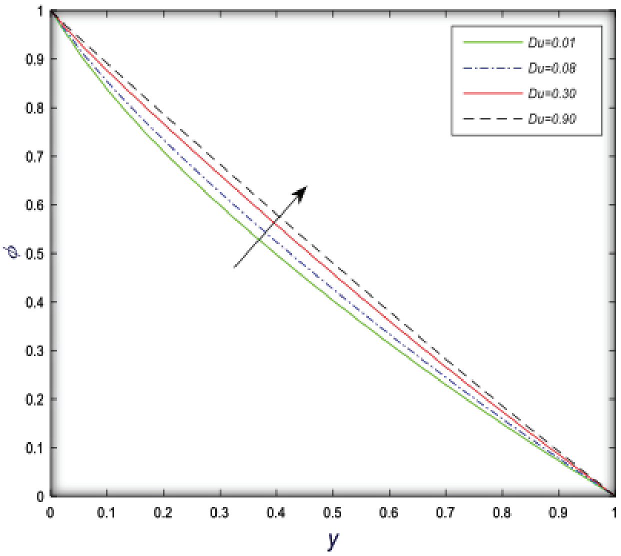

Figure 13. Influence of Du on the concentration profile when $Gm = 10$, $Gr = 7$, $\alpha = \pi/4$, $\delta = 1.5$, $Pr = 6.9$, $K = 0.1$, $E = 0.001$, $M = 2$, $Sc = 0.5$.

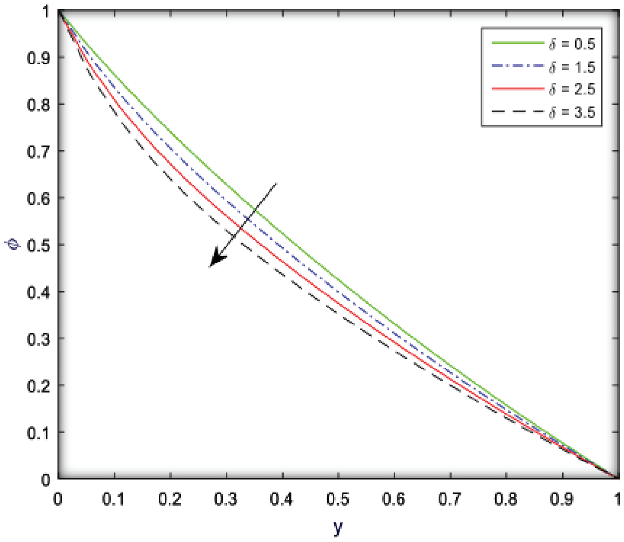

Figure 15. Sequel of δ on the concentration profile when $Gm = 10$, $Gr = 7$, $\alpha = \pi/4$, $Sc = 0.5$, $Pr = 6.9$, $K = 0.1$, $E = 0.001$, $M = 2$, $Du = 0.15$.

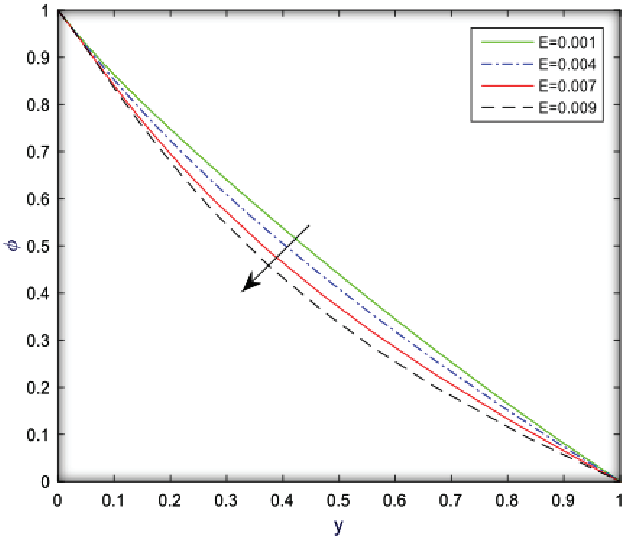

Figure 14. Effect of E on the concentration profile for $Gm = 10$, $Gr = 7$, $\alpha = \pi/4$, $\delta = 1.5$, $Pr = 6.9$, $K = 0.1$, $Sc = 0.5$, $M = 2$, $Du = 0.15$.

concentration gradient, which contributes to the development of fluid concentration.

Figures 14 and 15 grandstand the effect of Eckert number and thermophoresis on mass disposition. Figure 14 reveals that the concentration of the fluid tends to slow down as the Eckert number (E) increases. This is due to the increased prominence of viscous dissipation, leading to higher temperature and a reduction in concentration gradient. Furthermore, form Figure 15, we can see that concentration field decreases as thermophoresis parameter (δ) increases. When a high-density, low-diffusivity fluid species is subjected to high-velocity thermophoresis, its concentration decreases across the flow locale.

We are communicating the impacts of diverse parameters on Coefficient of Skin friction (τ), Nusselt number (Nu) and Sherwood number (Sh) in tabular shape rather than graphical representation and the actions of the parameters is understandable from Tables 1 to 3.

Upon review of Table 1, it is evident that the coefficient of skin friction demonstrates an escalation in response to heightened solutal Grashof and Eckert numbers, while it diminishes as the magnetic parameter and angle of inclination values increase.

We can see some important effects of flow attributes on the Nusselt number in Table 2. As shown in Table 2, an increase in the Prandtl number, Dufour effect, and Schmidt number leads to a hindering effect on the Nusselt number, but an increase in the Eckert number indicates the opposite.

In Table 3, it is observed that the Sherwood number changes as the flow parameters change. The table indicates that an increase in the Dufour effect and Eckert number increases the Sherwood number. However, the Schmidt number and thermophoresis parameter have opposite effects on the Sherwood number.

It should be mentioned that the overall physical actions of this problem coincide exceptionally well with the previously published writing (Palani and Arutchelvi [34], Ramesh *et al.* [40]), whether in graphical or tabular form.

Table 1. Coefficient of skin friction for variations of different parameters

M	Pr	Gr	Gm	δ	E	Sc	K	α	Du	τ (skin friction)
3 5 7 9	6.9	7	10	1.5	0.001	0.5	0.1	π/4	0.15	-2.0915 -2.4749 -2.8232 -3.1432
2	6.9	7	3 7 10 15	1.5	0.001	0.5	0.1	π/4	0.15	-3.5849 -2.9851 -2.5352 -1.7852
2	6.9	7	10	1.5	0.001 0.003 0.006 0.008	0.5	0.1	π/4	0.15	-2.5238 -2.2821 -2.0100 -1.7202
3	6.9	7	10	1.5	0.001	0.5	0.1	π/12 π/4 π/3 5π/12	0.15	-2.1854 -2.7105 -3.1307 -3.6200

Table 2. Nusselt number for variations of different parameters

M	Pr	Gr	Gm	δ	E	Sc	K	α	Du	Nu (Nusselt Number)
2	1.0 1.7 2.4 3.2	7	10	1.5	0.001	0.5	0.1	π/4	0.1	0.5774 0.4061 0.2937 0.2096
2	6.9	7	10	1.5	0.001 0.005 0.007 0.009	0.2	0.1	π/4	0.15	0.0885 0.1235 0.1474 0.1946
2	6.9	7	10	1.5	0.001	0.5	0.1	π/4	0.01 0.04 0.07 0.10	0.1346 0.1047 0.0803 0.0601
2	3.2	7	10	1.5	0.001	0.01 0.05 0.09 0.20	0.1	π/4	0.15	0.2977 0.2858 0.2742 0.2440

Table 3. Sherwood number for variations of different parameters

M	Pr	Gr	Gm	δ	E	Sc	K	α	Du	Sh (Sherwood Number)
2	6.9	7	10	1.5	0.001	0.15 0.50 0.90 1.50	0.1	π/4	0.15	-1.2360 -1.5982 -1.8419 -2.0564
2	6.9	7	10	0.5 1.5 2.5 3.5	0.010	0.5	0.1	π/4	0.15	-1.4203 -1.5966 -1.6930 -1.7520
2	6.9	7	10	1.5	0.001	0.5	0.1	π/4	0.01 0.08 0.30 0.90	-1.9154 -1.7258 -1.4327 -1.2057
2	3.2	7	10	1.5	0.001 0.004 0.007 0.009	0.5	0.1	π/4	0.08	-1.7235 -1.6794 -1.6271 -1.5775

CONCLUSION

This study explains the highlights of Dufour effect and energy dissipation in the natural convection of an MHD ((Magnetohydrodynamics)) electrically conducting viscous fluid through a permeable media on a tilted plate at a specific angle escorted by Thermophoresis. Utilizing resemblance changes, the commanding equations of the problem are converted to couple non-linear ordinary differential equations and are unravelled numerically using the MATLAB's solver bvp4c. The acquired numerical arrangements are correlated with already distributed outcomes and are instituted in the fabulous assertion. The impact of distinctive parameters on the Velocity, Temperature and Concentration distribution are lined and talked about.

1. The Thermophoresis parameter incorporates a comparable effect on fluid mobility. The presence of thermophoresis has a notable impact on the rates of heat and mass transfer, indicating potential uses in improving thermal management systems.
2. Increments in the magnetic field intensity led to impediments to fluid development.
3. Typical dimensionless velocities tend to extend with expanding Eckert number.
4. The impact of expanding the angle of inclination is to diminish the speed in addition to the viscous drag.
5. The thermal profile and the rate of heat transfer depreciate as the value of Dufour number increases, but very switch behaviour is noted in case of concentration profile and rate of mass transfer.
6. The temperature lessens with increases within the estimations of Schmidt number and Prandtl number.
7. Concentration profiles appear a slowing trend with increasing Eckert number and Schmidt number.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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