Journal of Advanced Zoology
ISSN: 0253-7214
Volume 44 Issue 5 Year 2023 Page 1480-1492

Dufour And Hall Effects On MHD Flow Past An Exponentially Accelerated Vertical Plate With Constant Temperature

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Abstract

In this problem analytics, the exact performance of the Dufour and Hall Effects coupled are used to study a magnetohydrodynamic flow on a vertical plate that is exponentially accelerated while keeping a constant temperature. A viscous fluid that is electrically conducting is incompressible and does not scatter in any medium. To resolve the temperature, concentration and velocity Elements of the fluid flow, the basic fundamental flow equations are cracked using the technique of Laplace Transforms. The Temperature, Concentration and Velocity Profiles explained in the graph are solved efficiently by applying MATLAB. The graph depicts an increase in several physical dimension parameters such as the DuFour number (Df), the Prandtl number (Pr), and the Thermal Grashof number (Gr), all of which contribute to a velocity increase. The velocity trend is reversed when the Hall parameter (m), Hartmann number (M), Mass Grashof number (Gm), and Schmidt number (Sc) are increased.

Keywords: In this context, concepts like magnetohydrodynamics, the Dufour effect, the Hall effect, mass diffusion, and the exponential distribution are utilised.

Introduction

The process (Thermodynamic) in which the temperature is unchanging is termed the Isothermal Process. Changes in the System occur slowly as it is allowed to adjust the reservoir temperature utilising heat exchange. The reservoir is connected with the system. Magnetohydrodynamics is a multidisciplinary field that applies to astrophysics, problems in engineering such as confinement of plasmas, cooling of liquid metals in (nuclear) reactors, to suppress instabilities and control the flow while casting during the process of metals, used to measure velocities using sensors that can survive in harsh environments too. The Hall Effect is most often employed in electrical engineering to determine whether positive or negative charges carry current. It's also utilised to establish magnetic field strength measurements, as well as fluid flow measurements in any fluid containing free charges. Because the Hall Effect is a dimensionless equation, it is now usual practise to use it as a research tool to investigate charges, drift velocities, and densities. When it comes to determining the electrical transport capacities of metals and semiconductors, Hall effect measurements are still a viable option. Magnetic field measurements, position and motion detectors, and other forms of optical sensors and devices are all based on the Hall effect. Sewing machines, machine tools, automobiles, medical equipment and computers are the Hall Effect Sensing Devices for industrial and consumer use. Hall effect sensor equipment is used in a variety of industries to produce high-quality magnetic switches.

The effects of rotation on the unsteady Magnetohydrodynamic flow of a linearly accelerated isothermal vertical plate were explored by D. Ranganayakulu[8] and colleagues, who discovered that as the rotation parameter is lowered, the velocity increases. J. Venkatesan[10] and colleagues studied an exact solution of a vertical plate in parabolic motion with mass flux and thermal radiation, and showed that the velocity develops rapidly near the plate, then decays to the free stream velocity as the plate travels away from the source. Gaurav Kumar[7] examined the impact of Soret and Dusty Fluid over an inclined porous plate and found that when the Soret Number and Dusty Fluid parameter increase, the velocity increases (see Figure 1). V. Visalakshi[11] and colleagues used a heat source to explore the effects of radiation on an unsteady Magnetohydrodynamic flow on an isothermal vertical plate that is exponentially accelerated with uniform mass, and found that the temperature rises when the heat source is present.

When D. Sarma and colleagues explored the combined effects of Hall Current, Rotation, and Soret Effect in a porous medium, they observed that the Hall current effect accelerated the secondary velocity fluid. Farhad Ali[1] and colleagues researched Heat and Mass Transfer in a Porous Medium with Free Convection and observed that the Hartmann number and the porosity factor had diametrically opposing impacts on velocity. The theoretical solution of Magnetohydrodynamic Flow through a vertical plate accelerated by the combined Hall and Rotation Effect is investigated when the rotation parameter is lowered, and exponential becomes axial and transversal velocity with decreasing rotation parameter values. Suba[16] et al. explored a transient Magnetohydrodynamic flow of an impulsively begun semi-infinite plate with Hall current and Chemical reaction in a rotating medium, finding that the heat and mass transfer rate rises as the radiation and chemical reaction parameters increase. The hall effect on an isothermal plate in the presence of a rotating fluid and a first-order chemical process was studied by Dhanajeya Kumar[6] and colleagues, who determined that the fluid approaches its maximum axial velocity. It was established that the Dufour effect was large enough that it could not be disregarded (Eckert[5] and Drake 1972).

Alam[2] studied the effects of Hall parameters on MHD flow on an inclined stretched sheet with produced heat and suction, and found that the main velocity reduces for magnetic characteristics while increasing for Hall and bouncy parameters (as well as for the magnetic parameter). Mopuri[12] investigated the Hall effect on MHD free convective flow through a porous plate with linked thermal radiation, heat absorption, and chemical reaction, and observed that when the Prandtl number was raised, primary and secondary velocity decreased. Opanunga[13] studied the hall and Joule effects on a pair of stress fluids with entropy and observed that when Joule heating is given to the fluids, the temperature increases. The growth of entropy is promoted as well. Barik[4] examined the effects of heat and mass transfer on the flow field velocity using a uniformly accelerated isothermal plate with a heat source and chemical reaction. He observed that when the heat source, chemical parameter, Schmidt, and Prandtl number are raised, the flow field velocity drops. Raju[14] studied MHD flow through a heat transfer rotating fluid in the presence of radiation effects and observed that when the chemical reaction parameter rose, the primary velocity dropped. Bhaskar[3] explored the flow on an isothermal vertical plate using magnetohydrodynamic flow exponentially accelerated with radiation effect and constant mass. Saravanan[9] looked on numerical analysis with radiation effect on an oscillating isothermal plate with constant mass flow on an oscillating isothermal plate with constant mass flux on an oscillating isothermal plate with constant mass flux.
Examining and studying the real-world performance of the Dufour Effect and the Hall Effect on magnetorheological flow over an exponentially accelerating vertical plate with constant temperature in a controlled setting is one of the goals of this research. One of the Laplace Transform techniques must be used to the scenario in order to solve the basic flow equations. To characterise the analytic solutions that have been provided, the exponential and complementary error functions will be applied.

Mathematical Analysis

We explored the Magnetohydrodynamic flow of a viscous fluid that is electrically conducting, incompressible, and does not scatter in any medium when confined within an infinite isothermal vertical plate, as reported in the literature, in this work. The x-axis has been aligned with the plate's motion (upward), while the y-axis has been aligned perpendicular to the x-axis. In compared to the surrounding environment, the flow is exposed to a consistent strength of Transverse Magnetic Field B0. The fluid concentration and temperature C_∞ and T_∞ are both considered to be at their starting levels at first. The plate starts to move exponentially in its plane at time t > 0 because of the plate's velocity, $u=u_0e^{at}$, and because the concentration and temperature of the plate are evenly raised to C_w and T_w and maintained constantly.

The basic fundamental flow equations, as approximated by Boussinesq's Approximations, are as follows: Because of the Hall Effect, the Momentum Equation will have two components.

$$\frac{\partial u}{\partial t} = \vartheta\frac{\partial^2 u}{\partial y^2} + g\beta(T - T_\infty) + g\beta^*(C - C_\infty) - \frac{\sigma\mu^2 B_0^2}{\rho(1+m^2)}(u + mv) \tag{1}$$

$$\frac{\partial v}{\partial t} = \vartheta\frac{\partial^2 v}{\partial y^2} + \frac{\sigma\mu^2 B_0^2}{\rho(1+m^2)}(mu - v) \tag{2}$$

$$\frac{\partial T}{\partial t} = \frac{k}{\rho C_P}\frac{\partial^2 T}{\partial y^2} + \frac{D_m K_T}{C_s C_P}\frac{\partial^2 C}{\partial y^2} \tag{3}$$

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial y^2} \tag{4}$$

The initial and terminal conditions are:

$$\left.\begin{array}{l} u = 0;\ v = 0;\ T = T_\infty;\ C = C_\infty\ \ for\ each\ y : t \le 0 \\ u = u_0 e^{\omega t}; v = 0; T = T_w; C = C_w\ at\ y = 0 :\ t > 0 \\ u \to 0; v \to 0; T \to T_\infty; C \to C_\infty\ as\ y \to \infty \end{array}\right\} \tag{5}$$

Making use of the dimensionless quantities listed below

$$\bar{y} = \frac{yu_0}{\vartheta}, \bar{t} = \frac{tu_0{}^2}{\vartheta}, \bar{u} = \frac{u}{u_0}, \theta = \frac{T - T_\infty}{T_w - T_\infty}, \bar{C} = \frac{C - C_\infty}{C_w - C_\infty}, Pr = \frac{\mu Cp}{k}, \quad Sc = \frac{\vartheta}{D}, \quad \mu = \vartheta\rho, \bar{\omega} = \frac{\omega\vartheta}{u_0{}^2},$$

$$Gm = \frac{g\beta^*\vartheta(C_w - C_\infty)}{u_0{}^3}, Gr = \frac{g\beta\vartheta(T_w - T_\infty)}{u_0{}^3}, M = \frac{\sigma\mu^2 B_0{}^2\vartheta}{\rho u_0{}^2(1+m^2)},\ Df = \frac{DmK_T(C_w - C_\infty)}{\vartheta CsCp(T_w - T_\infty)} \tag{6}$$

Equations (1) to (4) are transformed into the following dimensionless form,

$$\frac{\partial\bar{u}}{\partial\bar{t}} = \frac{\partial^2\bar{u}}{\partial\bar{y}^2} + Gr\theta + Gm\bar{C} - M(\bar{u} + m\bar{v}) \tag{7}$$

$$\frac{\partial\bar{v}}{\partial\bar{t}} = \frac{\partial^2\bar{v}}{\partial\bar{y}^2} + M(m\bar{u} - \bar{v}) \tag{8}$$

$$\frac{\partial\theta}{\partial\bar{t}} = \frac{1}{Pr}\frac{\partial^2\theta}{\partial\bar{y}^2} + Df\frac{\partial^2\bar{C}}{\partial\bar{y}^2} \tag{9}$$

$$\frac{\partial\bar{C}}{\partial\bar{t}} = \frac{1}{Sc}\frac{\partial^2\bar{C}}{\partial\bar{y}^2} \tag{10}$$

The initial and terminal conditions become

$$\left.\begin{array}{l} \bar{u} = 0;\ \bar{v} = 0;\ \theta = 0;\ \bar{C} = 0 \quad \forall\ \bar{y}\ : \bar{t} \le 0 \\ \bar{u} = e^{\overline{\omega t}};\ \theta = 1;\ \bar{C} = 1 \quad at\ \bar{y} = 0 :\ \bar{t} > 0 \\ u \to 0; v \to 0;\ \theta \to 0; \bar{C} \to 0 \quad as\ \bar{y} \to \infty \end{array}\right\} \tag{11}$$

Dropping bars from (7) to (11) and adding (7) and (8) q = u + iv, we get

$$\frac{\partial q}{\partial t} = \frac{\partial^2 q}{\partial y^2} + Gr\theta + GmC - aq \quad (12)$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{Pr}\frac{\partial^2 \theta}{\partial y^2} + Df\frac{\partial^2 C}{\partial y^2} \quad (13)$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} \quad (14)$$

Where a= $M(1 - im)$

The initial and boundary conditions become

$$\left.\begin{array}{ll} u = 0;\ v = 0;\ \theta = 0;\ C = 0 & \forall\, y:\ t \leq 0 \\ u = e^{\omega t};\ \theta = 1;\ C = 1 & at\ y = 0:\ t > 0 \\ u \to 0; v \to 0;\ \theta \to 0; C \to 0 & as\ y \to \infty \end{array}\right\} \quad (15)$$

If the boundary conditions (15) are fulfilled, one of the techniques in the Laplace Transform is used to solve the dimensionless equations (12) to (14)

The solution is obtained as under

$$C = erfc\left(\eta\sqrt{Sc}\right) \quad (16)$$

$$\theta = erfc\left(\eta\sqrt{Pr}\right) + \frac{DfPrSc}{Sc-Pr}\left[erfc\left(\eta\sqrt{Pr}\right) - erfc\left(\eta\sqrt{Sc}\right)\right] \quad (17)$$

And $q = q_1 + d(q_2 - q_3) + e(q_4 - q_5)$ (18)

Where $q_1 = \frac{e^{\omega t}}{2}\left[e^{-2\eta\sqrt{(\omega+a)t}} erfc\left(\eta - \sqrt{(\omega+a)t}\right) + e^{2\eta\sqrt{(\omega+a)t}} erfc\left(\eta + \sqrt{(\omega+a)t}\right)\right]$

$$q_2 = -\frac{1}{2b}\left[e^{-2\eta\sqrt{at}} erfc\left(\eta - \sqrt{at}\right) + e^{2\eta\sqrt{at}} erfc\left(\eta + \sqrt{at}\right)\right] + \frac{e^{bt}}{2b}\left[e^{-2\eta\sqrt{(a+b)t}} erfc\left(\eta - \sqrt{(a+b)t}\right) + e^{2\eta\sqrt{(a+b)t}} erfc\left(\eta + \sqrt{(a+b)t}\right)\right]$$

$$q_3 = -\frac{1}{b} erfc\left(\eta\sqrt{Pr}\right) + \frac{e^{bt}}{2b}\left[e^{-2\eta\sqrt{Prbt}} erfc(\eta\sqrt{Pr} - \sqrt{bt}) + e^{2\eta\sqrt{Prbt}} erfc\left(\eta\sqrt{Pr} + \sqrt{bt}\right)\right]$$

$$q_4 = -\frac{1}{2c}\left[e^{-2\eta\sqrt{at}} erfc\left(\eta - \sqrt{at}\right) + e^{2\eta\sqrt{at}} erfc\left(\eta + \sqrt{at}\right)\right] + \frac{e^{ct}}{2c}\left[e^{-2\eta\sqrt{(a+c)t}} erfc\left(\eta - \sqrt{(a+c)t}\right) + e^{2\eta\sqrt{(a+c)t}} erfc\left(\eta + \sqrt{(a+c)t}\right)\right]$$

$$q_5 = -\frac{1}{c} erfc\left(\eta\sqrt{Sc}\right) + \frac{e^{ct}}{2c}\left[e^{-2\eta\sqrt{Scct}} erfc(\eta\sqrt{Sc} - \sqrt{ct}) + e^{2\eta\sqrt{Scct}} erfc\left(\eta\sqrt{Sc} + \sqrt{ct}\right)\right]$$

$$d = \frac{Gr}{Pr-1} + \frac{DfPrScGr}{(Sc-Pr)(Pr-1)}\ and\ e = \frac{Gm}{Sc-1} - \frac{DfPrScGr}{(Sc-Pr)(Sc-1)}$$

We've reduced the various constants used in the previous mathematical analysis to conserve space in the Nomenclature Section.

Results and Discussion

The basic fundamental flow equations of the issue are cracked using the Laplace Transforms after the boundary conditions (12) to (15) are fulfilled. This is for a primary magnetohydrodynamic flow across a semi-infinite vertical plate with constant mass and temperature that is exponentially accelerated. The answer has been worked out and cracked analytically, and the equations (16) to (18) disclose it (19). (18). We can calculate the possible effects of the heat sources on the plate as it moves with velocity q in its plane throughout its motion using the answers we've discovered. Numerical simulations are used to evaluate different values of the "Hall parameter (m), Dufour Number (Df), Hartmann Number (M), (both) Thermal and Mass Grashof Number (both Gm and Gr), Prandtl Number (Pr), Schmidt Number (Sc), and time (t)". Because the flow occurs in the air medium, the Prandtl number (Pr) is 0.71 in this situation. According to common perception, the Schmidt Numbers (2.01, 3, 4, and 4) signify Ethyl Benzene, Helium, and Water Vapour, respectively. The research of the effects of free convection currents may be considerably improved in its efficiency and efficacy by using the Thermal Grashof Number (Gr), which is made up of integer values. The "Velocity Trend, Temperature Trend, and Concentration Trend" are studied in Figures 1 to 14, while the other parameters stay constant. Following the calculations, it was determined that the combined effects of the Dufour and the Hall may be employed as a study tool to help in the efficiency of the flow equations conclusion.

Graphs

Graphical analysis is used to show how the Dufour and Hall Effects combine to generate a Magnetohydrodynamic flow with constant temperature in a vertical semi-infinite plate that is accelerated exponentially. In graphs 1 through 14, the variations in temperature, concentration, and velocity fluctuations in this combined effect of Dufour and Hall are detailed.

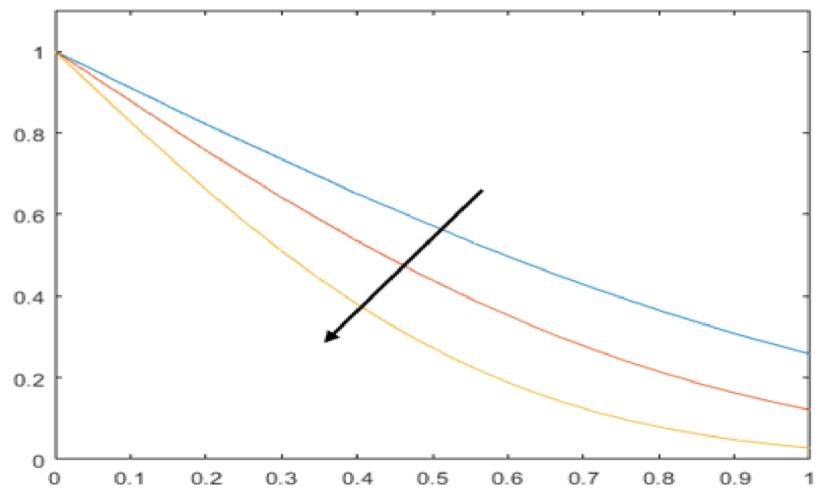

Figure 1. Concentration Trend for Sc

In terms of the concentration field, FIGURE 1 displays the behaviour of the concentration field for the values Sc=0.16, 0.3, and 0.6 and the time t=0.2. When the Schmidt number (Sc) grows in value, as evidenced by the rising values of Sc, a droop in Wall Thickness [(i.e.) concentration] may be noted. As the Schmidt Number (Sc) grows, concentration tends to fall, and vice versa.

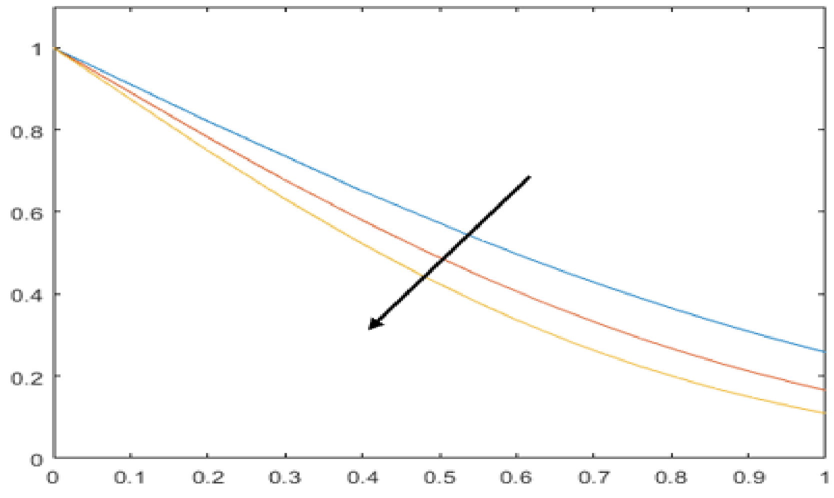

Figure 2. Concentration Trend for t

Figure 2 depicts the behaviour of the concentration field for Time t = 1, 1.5, and 2 as well as the Schmidt Number, Sc=0.16. The fluid expands and contracts as time (t) passes in response to a gradual decrease in Wall Thickness. As the period of time (t) increases, concentration tends to decrease.

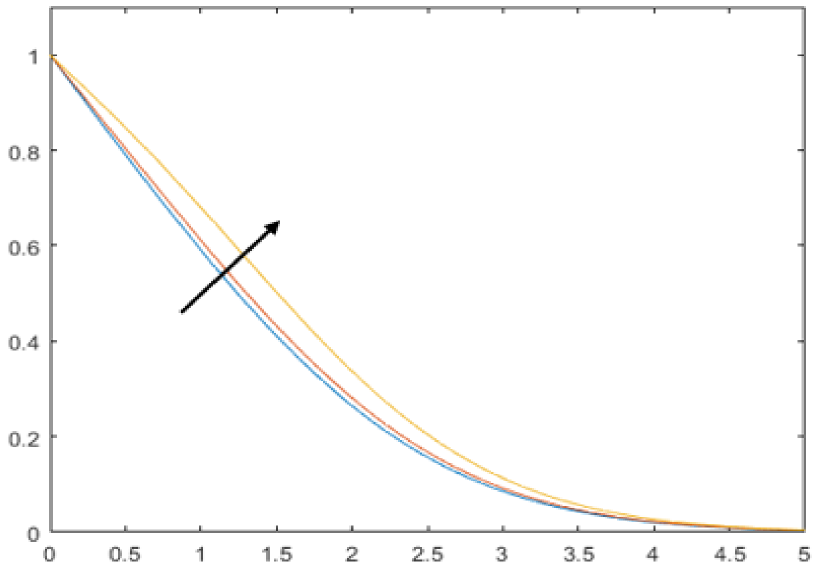

Figure 3. Temperature trend for Df

The temperature's behaviour may be discussed in further detail using the Dufour Number Df = 0.15, 0.23, and 0.5, the "Schmidt Number Sc=2.01, the Prandtl Number Pr = 0.71, and the time t=1". The energy flow induced by a mass concentration gradient that develops as a consequence of a number of irreversible processes functioning in concert is known as the Dufour effect. We can detect a minor rise in the Temperature measure in combination with a considerable increase in the Dufour Number (Df), which elevates the level of the flow field, due to the operation of the Buoyancy Effect. In general, as the Dufour Number (Df) grows, so does the temperature.

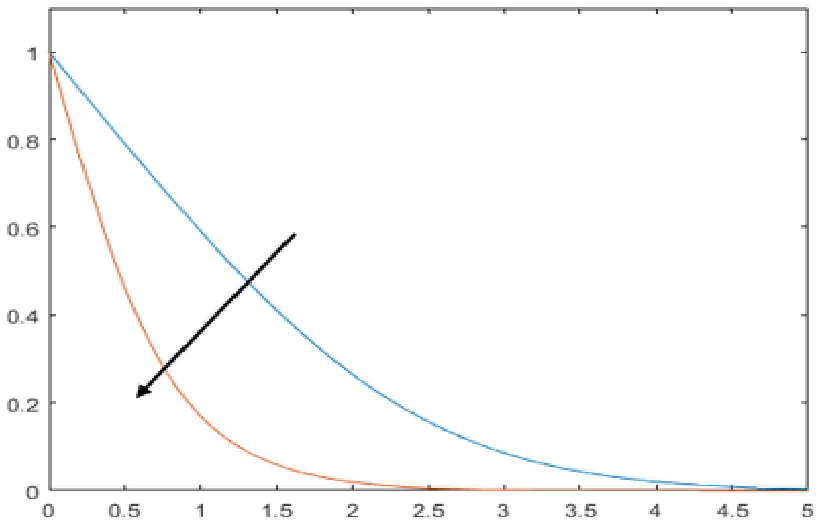

Figure 4. Temperature trend for Pr

The "Schmidt Number Sc=2.01 and the Dufour Number Df=1.5" explain the temperature behaviour for "Prandtl Number Pr=0.71 and 7, respectively, and the time t=1" as given in Figure 4. Air has a Prandtl Number of 0.71, whereas water has a Prandtl Number of 7. When comparing the temperatures of fluid flows in air and water, the combined impact of Dufour and Hall has an effect on temperature in such a way that the temperature of the fluid flow in air is higher than the temperature of the fluid flow in water. When the Prandtl Number (Pr) increases, the temperature tends to drop.

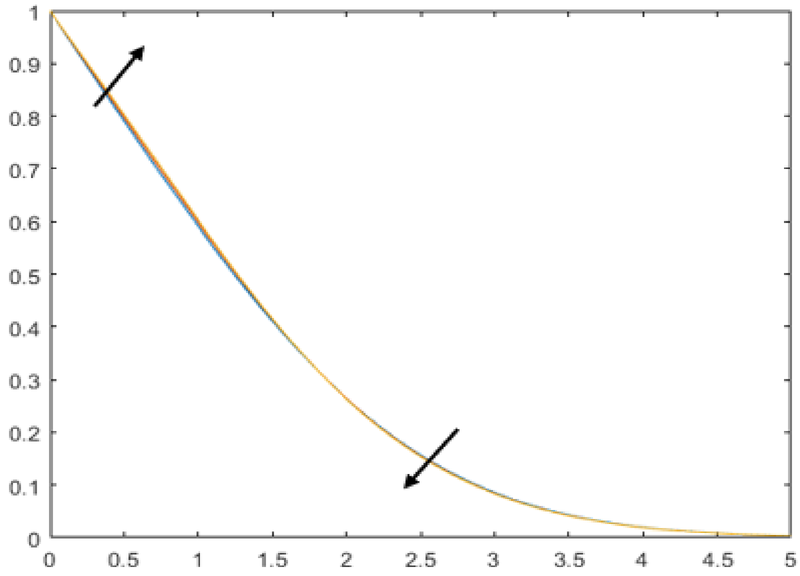

Figure 5. Temperature trend for Sc

For the Schmidt Number Sc=2.01, 3, 4, Prandtl Number Pr= 0.71, Dufour Number Df=1.5, and Time t=1, Figure 5 displays the temperature behaviour for the Schmidt Number Sc=2.01, 3, 4, and Prandtl Number Pr= 0.71. When the combined effects of Dufour and Hall are present, the temperature rises in such a way that the Schmidt Number (Sc) rises, indicating that the temperature tends to climb. Following point (0.3), there is a temperature fluctuation, and it is easy to see that the trend is reversing, culminating in a decrease in temperature.

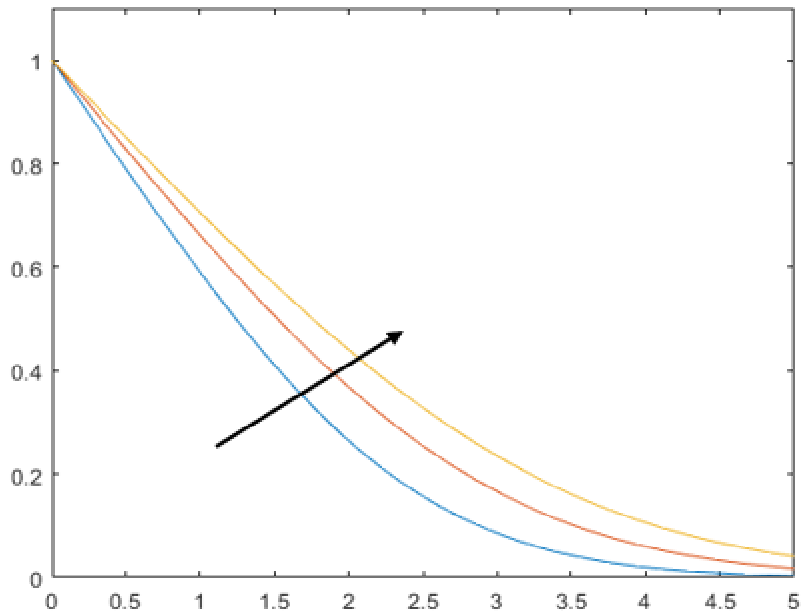

Figure 6. Temperature trend for t

The temperature behaves as indicated in Figure 6 for the values of Time t =1, 1.5, 2, and 3. The temperature behaviour is explained by the Dufour Number Df=0.15, the Prandtl Number Pr=0.71, and the Schmidt Number Sc=2.01. The fluid's reaction to an increase in temperature got increasingly evident as time (t) passed. With the passage of time (t), the temperature tends to increase.

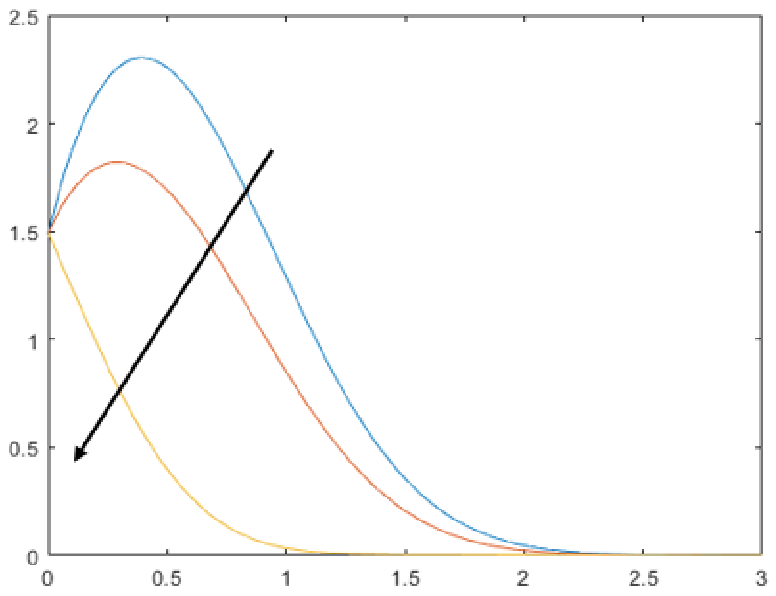

Figure 7. Velocity trend for M

Figure 7 explains the behaviour of the velocity, which is influenced by the Hartmann Number (M). The velocity attains its maximum value when M = 0.8 and 1 separately near the plate. When M = 2, the velocity attains its minimum value. Here we perceive a rapid increase in the fluid speed when M is minimum. The Hartmann number continues to increase as there is a drop in the velocity. As M increases, velocity tends to decrease.

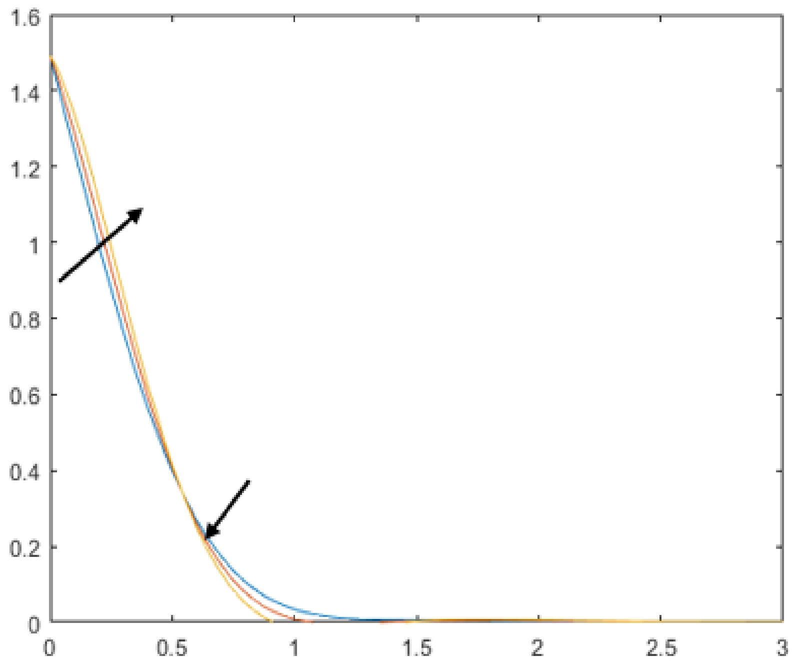

Figure 8. Velocity trend for Df

Figure 8 explains the behaviour of the velocity, which is influenced by the Dufour Number (Df). As Dufour Number (Df) increases, velocity also increases, and there is a reverse in the trend after some point (0.35), i.e., the velocity decreases as Dufour number (Df) increases.

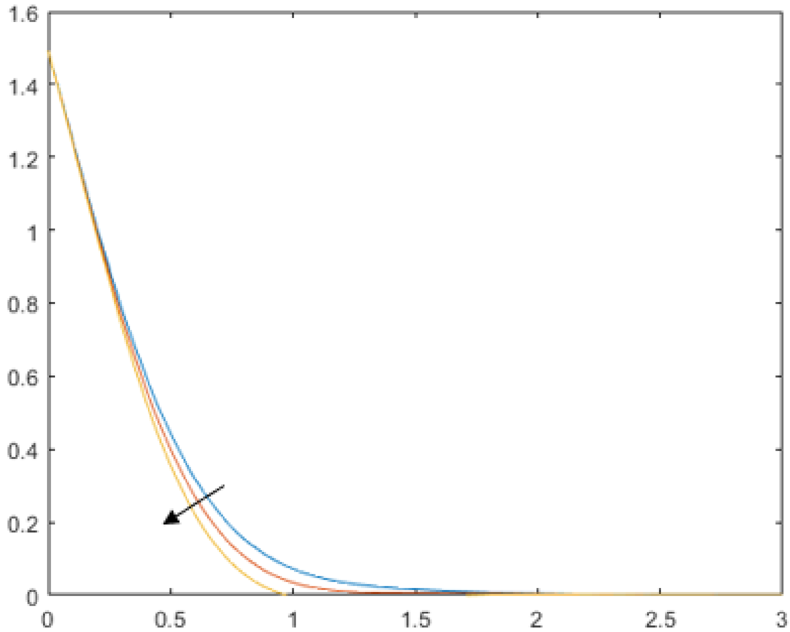

Figure 9. Velocity trend for Gm

Figure 9 explains the behaviour of the velocity, which is influenced by the Mass Grashof Number (Gm). The velocity seems to travel steadily at the beginning of the flow. There is a reverse in the trend after some point (0.35), i.e., here comes a reduction in the speed as the Mass Grashof Number (Gm) upsurges. As Mass Grashof Number (Gm) increases, velocity tends to decrease.

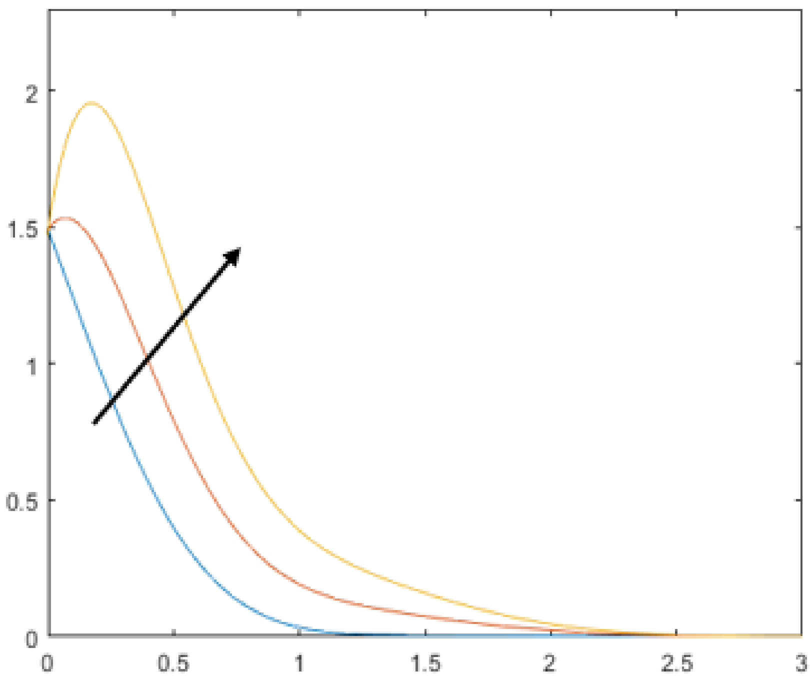

Figure 10. Velocity trend for Gr

Figure 10 demonstrates how the Thermal Grashof Number (Gr), which is defined as the "ratio of buoyancy to the viscous force acting on a fluid", influences fluid velocity. The velocity attains its maximum value when Gr is raised. The rise may chiefly have been due to the buoyancy effect. As Thermal Grashof Number (Gr) increases, velocity tends to increase.

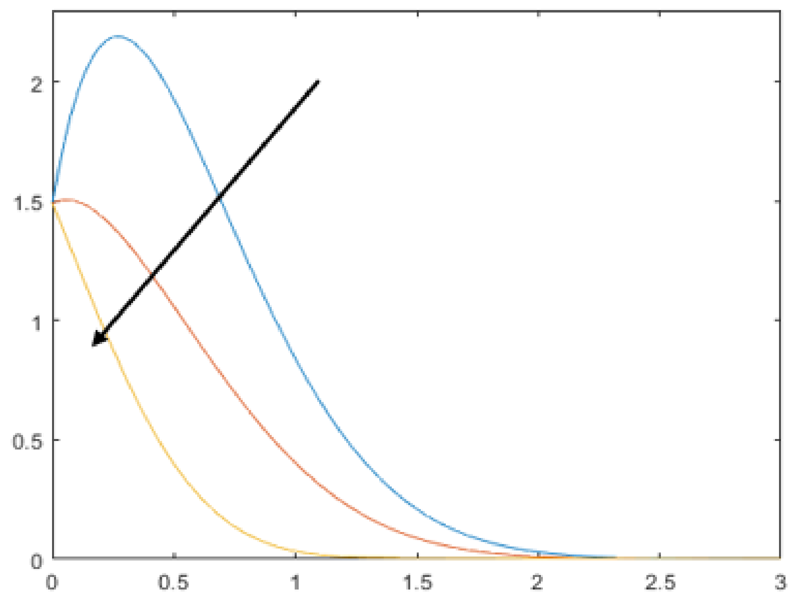

Figure 11. Velocity trend for m

Figure 11 explains the behaviour of the velocity, which is influenced by Hall Parameter (m). The velocity diminishes when the Hall parameter is raised until it reaches its minimum value. This pattern can be seen for the "Hall parameter m = 1, 2, 3, Hartman Number M = 2, Prandtl Number Pr = 0.71, Schmidt Number Sc = 2.01, Dufour Number Df = 0.5, Thermal cum Mass Grashof Number Gm Gr = 10, w = 2, and time, t = 0.2, as well as the Prandtl Number Pr, Schmidt Number Sc, Prandtl Number M, and Dufour Number Df". When the Hall Parameter (m) is raised, the velocity tends to decrease.

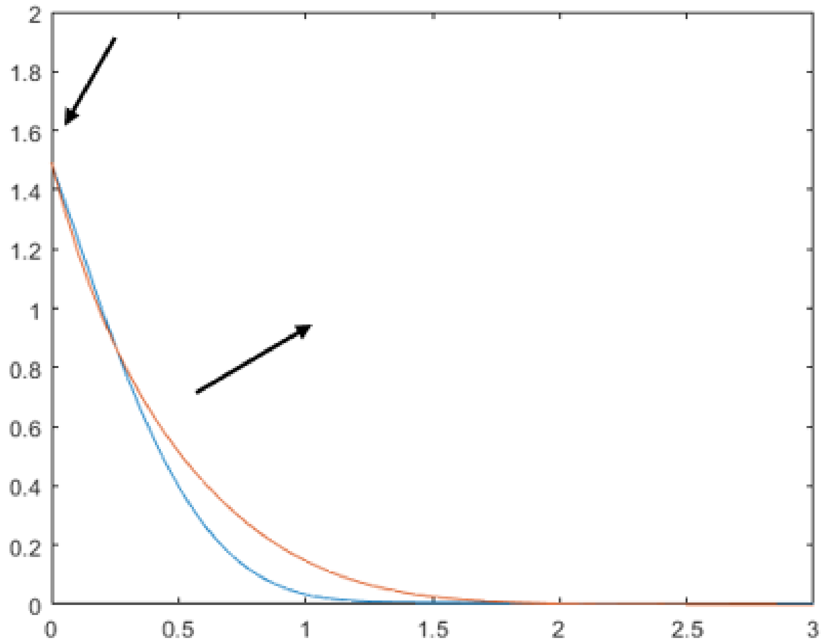

Figure 12. Velocity trend for Pr

The Prandtl number has an effect on the velocity behaviour, as seen in Figure 12 (right) (Pr). As the pressure (Pr) rises, the fluid's speed tends to increase. After point (0.8), there is a change in velocity, showing that the trend has simply returned, resulting in a decrease in velocity. This is because fluids with a higher Pr will have a higher viscosity, which is thick enough to considerably obstruct flow.

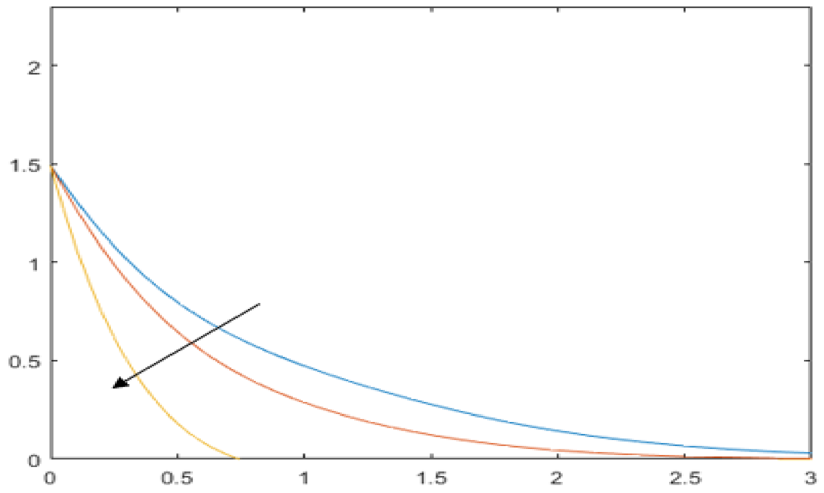

Figure 13. Velocity trend for Sc

Figure 13 depicts the velocity's behaviour, which is determined by the Schmidt Number. (Sc). We may see a reduction in fluid speed at the boundary between two fluids when the Schmidt Number (Sc) is raised. The trend is for velocity to decrease as the Schmidt Number (Sc) increases.

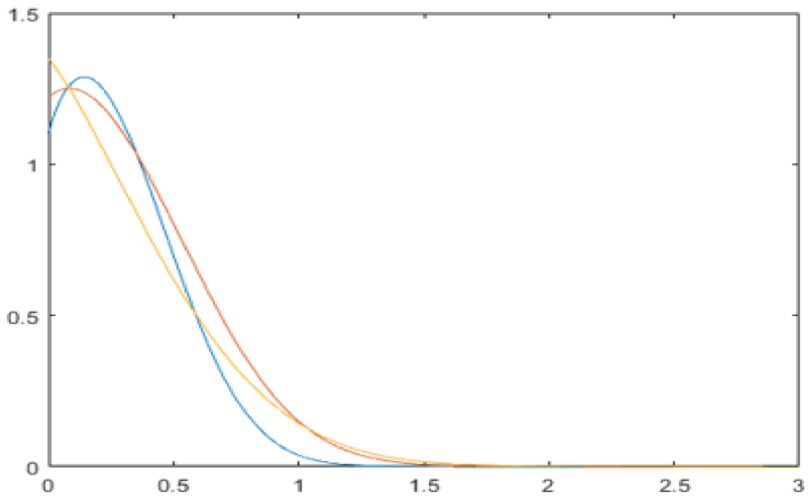

Figure 14. Velocity trend for t

Figure 14 explains the behaviour of the velocity, which is influenced by time (t). The graph shows a greater fluctuation in the velocity with the time (t). As the Time (t) increases, there is a total fluctuation in the velocity trend.

Conclusion

This paper investigates and analyses the real-world performance of the "Dufour Effect and the Hall Effect" on Magnetohydrodynamic Flow past an Exponentially Accelerated semi-infinite Vertical Plate with constant temperature.The basic fundamental flow equations are cracked by one of the techniques in Laplace Transform. Understanding the findings better by all the results is interpreted with the help of graphs using MATLAB application.

The outcomes of the study are:

1. As time flew, we can observe a great fluctuation in the velocity, a decent increase in temperature and a gradual decrease in the wall concentration.
2. As seen in the graph below, increasing the Schmidt Number (Sc) reduces the wall concentration as well as the variance in temperature and velocity in the fluid.
3. When Dufour Number (Df) is increased considerably, there is a slight increase in the temperature and velocity and conversely, reverse in the speed of the fluid and reaches zero levels in the freestream.

4. When we induce the magnetic field parameter initially, there is a rapid increase in the fluid speed. However, it gradually decreased when the magnetic field parameter is further induced in the fluid.
5. The velocity works the same manner when dealing with a lower Hall parameter (m) as it does when dealing with a greater Hartmann Number (M).

Appendix:
Dimensional Quantities:
(u, v, w) Components of velocity field q
(x, y, z) Cartesian Co-ordinates
m "Hall parameter"
g "Acceleration due to gravity"
β "Volumetric Co-efficient of thermal expansion"
β^* "Volumetric Co-efficient of Concentration expansion"
t "Time"
T "Temperature of fluid"
T_∞ "The temperature of the plate at y→ ∞"
T_w "The temperature of the plate at y= 0"
C "Species concentration in the fluid"
C_∞ "Species concentration at y→ ∞"
C_w "Species concentration at y=0"
C_p "Specific heat at constant pressure"
C_s "Concentration Susceptibility"
υ "Kinematic Viscosity"
ρ "Density"
k "Thermal Conductivity of the fluid"
D "Mass diffusion constant"
K_T "Thermal diffusion ratio"
D_m "Effective mass diffusivity rate"
B_0 "Uniform magnetic field"
σ "Electrical conductivity"

Non-Dimensional Quantities:
$(\bar{u}, \bar{v}, \bar{w})$ Non-Dimensional velocity components
M "Hartmann number"
Gr "Thermal Grashof number"
Gm "Mass Grashof number"
Pr "Thermal Prandtl number"
Df "Dufour number"
Sc "Schmidt number"
θ "Dimensionless Temperature"
$\bar{C}$ "Dimensionless Concentration"
$\bar{t}$ "Dimensionless Time"

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