Dufour and Hall Effects on MHDFlow past an Exponentially Accelerated Vertical Plate with Variable Temperature and Mass Diffusion

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Abstract: In this problem approach, the combined study of the Dufour Effect and Hall Effect on a Magnetohydrodynamic flow past an Exponentially Accelerated Vertical Plate with varying Temperature and Mass Diffusion. An electrically conducting incompressible viscous fluid in a non-scattering medium is considered here. Also, we have applied the basic fundamental of fluid flow equations for the components such as Temperature, Velocity and Concentration was acquired by the Laplace Transforms Technique. The graphical representation for various parameters such as Schmidt Number, the Magnetic Field Parameters, Dufour Number, Time, Prandtl Number and Grashof Number involved in the equations was originated using MATLAB software. It is monitored that there is a drop in the temperature and velocity when the Prandtl number is raised. The graph also validates an increase in temperature when the Schmidt number is increased. After some point (0.5), there is a sudden drop in the temperature.

Keywords: Magnetohydrodynamics, Dufour effect, Hall effect, vertical plate, exponential, mass diffusion.

1. Introduction

Every single movement in this universe is based on thermodynamic processes such as Heat Dissipation and Mass Transfer. For example, the temperature in the human body, walking, talking, working, and household items until space technology depends on this Heat Dissipation and Mass Transfer. Numerous Research Scholars have already studied, explored, and discovered their findings till now, and still, our exploration never ends.

The movement of an electrically conducting fluid in a Magnetic Field is studied in one of the branches of fluid dynamics, i.e., Magnetohydrodynamics. Out of numerous applications in Magnetohydrodynamics, it is also applied in astrophysics and geophysics too. Laplace Transforms is the best suited analytical technique to solve the basic fundamental fluid flow equations of Magnetohydrodynamic flow.

The study of Magnetohydrodynamic flow plays a vital role in Magnetohydrodynamic generators. The earliest application of Magnetohydrodynamics in engineering is the use of electromagnetic stirring. An electrically conducting incompressible viscous fluid in the influence of the Magnetic Field plays a major role in infinite applications such as geophysics, astrophysics, direct energy conversion.

(Soundalgekar., 1979) studied the influence of mass transfer and the flow of the liquid brought about by the Gravitational Force. (Muthucumaraswamyet al., 2013)analysed that the Plate Temperature level and the Plate Concentration level are linearly increasing near the plate with time and found increasing velocity with a decreasing Magnetic field. Hall effects on Magnetohydrodynamic flow were studied by (Muthucumaraswamy et al., 2014)and found that with an increase in Prandtl number, there is a depression in the value of the temperature of the plate. In the paper written by (Reddy et al.,2012), it was analysed and detected that an elevation in radiation parameter results in the fall of Velocity and Temperature. Dufour effects on Magnetohydrodynamic flow in an accelerated plate through porous media were studied by (Rajput and Gupta., 2016).(Muthucumaraswamy and Jeyanthi., 2014)analysed the Hall effects on Magnetohydrodynamic flow in the presence of a rotating fluid on a boundless vertical plate with Chemical Reaction.

Dufour effect on unsteady Magnetohydrodynamic flow past an inclined oscillating plate was studied by (Rajput and Kumar., 2016) and found that the fluid velocity drops when there is a rise in the angle of inclination. Chemical Reaction and Hall Effect on Magnetohydrodynamic Flow in the presence of Rotating Fluid was analysed by (Muthucumaraswamy and Jeyanthi., 2016) and observed that increase in K results in the fall of axial velocity and rise in transient velocity. Dufour Effect on unsteady Free Convection Magnetohydrodynamic Flow through a porous media was analysed by (Rajput and Kanaujia., 2016)and found a fall in the skin friction of the fluid whenever there is a rise in the values of Mass Grashof Number.

(Rajput and Gupta., 2016) analysed the study of MHD flow past a vertical plate in the presence of Hall current with variable temperature. They found that the primary velocity increases and secondary velocity decrease with the Hall parameter. (Pandyaet al., 2017)analysed the combined effect of radiation, Soret, Dufour and Chemical reaction on a Dusty fluid. They revealed that the concentration decreases first and then increases with the radiation parameter. (Chand et al., 2013)studies the effect of Hall current with rotation of a Magnetohydrodynamic flow of an oscillating dusty fluid in a porous medium and found that with increasing hall and rotation parameter, the velocity of the fluid and dust particle decreases. (Seth et al., 2016) analysed the Magnetohydrodynamic free convection flow with hall effect in a moving vertical plate with ramped temperature. They concluded that the critical time rampedness and thermal radiation reduces the heat transfer rate, whereas the heat adsorption rate is reversed. (Rajput and Kumar., 2018)analysed the rotation and radiation effects on an inclined plate with variable temperature in the presence of hall current. They concluded that the velocity descends with the radiation parameter. (Rout and Pattanayak., 2013)studied the chemical reaction and radiation effect on an exponentially accelerated vertical plate with variable temperature in a porous medium in the presence of a heat source. They found that when the radiation parameter increases, the temperature profile also increases due to increased convection in the boundary layer. (Srihari., 2018) analysed Soret, Dufour and radiation effect on unsteady double-diffusive flow. They found that increasing the velocity and solution thickness of the boundary increase with increasing values of the Soret number.(Seth et al., 2014) investigated the effects of hall current and rotation. They found that both accelerated the secondary velocity in the boundary layer. (Muthucumaraswamy andPrema., 2016)investigated the Hall effects on unsteady magnetohydrodynamic flow on an exponentially accelerated isothermal infinite vertical plate. They found that an increase in radiation parameter increases the temperature and the Prandtl number decrease increases the temperature.

We have studied and investigated the Dufour Effect and Hall effects on Magnetohydrodynamic flow over an exponentially accelerated vertical plate by varying temperature and mass diffusion in this work. In solving the basic fundamental fluid flow equations, the Laplace Transform technique was used. The mathematical solutions that are obtained will be in terms of the exponential and complementary error function. This kind of study boosts efficiency in the magnetic controlling ability of molten iron in the steel industry. In nuclear reactors for cooling liquid metals, in semiconducting materials, magnetic Suppression of molten iron, Meteorology.

2. Mathematical Analysis

We have considered the Magnetohydrodynamic movement of an Electrically Conducting Viscous Incompressible Fluid in an infinite vertical plate in this work. Here we have taken the x-axis in the upward direction in the direction of motion of the plate, and the y-axis is normal to the x-axis. A Transverse Magnetic Field $B_0$of uniform strength is applied to the flow. Due to its negligible effects, the Viscous Dissipation and induced magnetic field have been ignored. Initially, the fluid concentration C_∞ and temperature T_∞. It is assumed to be at rest. With velocity $u=u_0e^{at}$, and the concentration and temperature of the plate are raised to C_w and T_w, respectively, the plate starts moving exponentially in its plane at time $t > 0$.

Under Boussinesq's Approximations, the ruling equations are as follows:

There will be two components for Momentum Equation due to Hall Effect.

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

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

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

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial y^2} \quad (4)$$

The initial and terminal conditions are:

$$\left.\begin{array}{c} u = 0;\ v = 0;\ T = T_\infty;\ C = C_\infty for\ each\ y : t \le 0 \\ u = u_0 e^{\omega t}; v = 0; T = T_\infty + (T_w - T_\infty)\frac{u_0^2 t}{\vartheta}; C = C_\infty + (C_w - C_\infty)\frac{u_0^2 t}{\vartheta}\ at\ y = 0 :\ t > 0 \\ u \to 0; v \to 0; T \to T_\infty; C \to C_\infty\ as\ y \to \infty \end{array}\right\} \quad (5)$$

Using the following dimensionless quantities

$$\bar{y} = \frac{yu_0}{\vartheta}, \bar{t} = \frac{tu_0{}^2}{\vartheta}, \bar{u} = \frac{u}{u_0}, \theta = \frac{T - T_\infty}{T_w - T_\infty}, \bar{C} = \frac{C - C_\infty}{C_w - C_\infty}, Gm = \frac{g\beta^*\vartheta (C_w - C_\infty)}{u_0{}^3}, Gr = \frac{g\beta\vartheta\,(T_w - T_\infty)}{u_0{}^3}, M = \frac{\sigma\mu^2 B_0{}^2\vartheta}{\rho u_0{}^2(1+m^2)},$$

$$Pr = \frac{\mu Cp}{k},\ Sc = \frac{\vartheta}{D},\ \mu = \vartheta\rho, \bar{\omega} = \frac{\omega\vartheta}{u_0{}^2}, Df = \frac{Dm\,K_T\,(C_w - C_\infty)}{\vartheta CsCp\,(T_w - T_\infty)} \quad (6)$$

Equations (1 - 4) are transformed into dimensionless form,

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

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

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

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

The initial and terminal conditions become

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

Dropping bars from (7) to (11) and to solve equation (7) and (8) by adding (7) and (8) and introducing the complex velocity q = u + iv, we get the combined equations as (12)

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

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

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

Where a= $M(1 - im)$

with the following initial and terminal conditions:

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

subject to the boundary conditions (15), the dimensionless equations (12) to (14) solved by the Laplace Transform technique, the solution is obtained as under

$$C = t[(1+2\eta^2 Sc)erfc(\eta\sqrt{Sc}) - \frac{2\eta\sqrt{Sc}}{\sqrt{\pi}}e^{-\eta^2 Sc}] \quad (16)$$

$$\theta = \left[1+\frac{DfPrSc}{Sc-Pr}\right]t\left[(1+2\eta^2 Pr)erfc(\eta\sqrt{Pr}) - \frac{2\eta\sqrt{Pr}}{\sqrt{\pi}}e^{-\eta^2 Pr}\right] - \frac{DfPrSc}{Sc-Pr}\, t\left[(1+2\eta^2 Sc)erfc(\eta\sqrt{Sc}) - \right.$$
$$2\eta Sc\pi e{-}\eta 2Sc \quad (17)$$

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

Where,

$$q_1 = \frac{e^{\omega t}}{2}\left[e^{-2\eta\sqrt{(\omega+a)t}}erfc\left(\eta - \sqrt{(\omega+a)t}\right) + e^{2\eta\sqrt{(\omega+a)t}}erfc\left(\eta + \sqrt{(\omega+a)t}\right)\right] \quad (18.1)$$

$$q_2 = -\frac{1}{2b^2}[e^{-2\eta\sqrt{at}}erfc(\eta-\sqrt{at}) + e^{2\eta\sqrt{at}}erfc(\eta+\sqrt{at})] - \frac{t}{2b}[e^{-2\eta\sqrt{at}}erfc(\eta-\sqrt{at}) + e^{2\eta\sqrt{at}}erfc(\eta +$$
$$at{-}\eta t2bae{-}2\eta aterfc\eta{-}at{-}e2\eta aterfc\eta{+}at{+}ebt2b2e{-}2\eta a{+}bterfc\eta{-}a{+}bt{+}e2\eta a{+}bterfc\eta{+}a{+}bt$$
(18.2)

$$q_3 = -\frac{1}{2c^2}[e^{-2\eta\sqrt{at}}erfc(\eta-\sqrt{at}) + e^{2\eta\sqrt{at}}erfc(\eta+\sqrt{at})] - \frac{t}{2c}[e^{-2\eta\sqrt{at}}erfc(\eta-\sqrt{at}) + e^{2\eta\sqrt{at}}erfc(\eta +$$
$$at{-}\eta t2cae{-}2\eta aterfc\eta{-}at{-}e2\eta aterfc\eta{+}at{+}ect2c2e{-}2\eta a{+}cterfc\eta{-}a{+}ct{+}e2\eta a{+}cterfc\eta{+}a{+}ct$$
(18.3)

$$q_4 = -\frac{1}{b^2}erfc(\eta\sqrt{Pr}) - \frac{t}{b}[\left[(1+2\eta^2 Pr)erfc(\eta\sqrt{Pr}) - \frac{2\eta\sqrt{Pr}}{\sqrt{\pi}}e^{-\eta^2 Pr}\right] + \frac{e^{bt}}{2b^2}[e^{-2\eta\sqrt{Prbt}}erfc(\eta\sqrt{Pr} - \sqrt{bt}) +$$
$$e^{2\eta\sqrt{Prbt}}erfc(\eta\sqrt{Pr} + \sqrt{bt})] \quad (18.4)$$

$$q_5 = -\frac{1}{c^2}erfc(\eta\sqrt{Sc}) - \frac{t}{c}[\left[(1+2\eta^2 Sc)erfc(\eta\sqrt{Sc}) - \frac{2\eta\sqrt{Sc}}{\sqrt{\pi}}e^{-\eta^2 Sc}\right] + \frac{e^{ct}}{2c^2}[e^{-2\eta\sqrt{Scct}}erfc(\eta\sqrt{Sc} - \sqrt{ct}) +$$
$$e^{2\eta\sqrt{Scct}}erfc(\eta\sqrt{Sc} + \sqrt{ct})] \quad (18.5)$$

$$d = \frac{DfPrScGr}{(Sc-Pr)(Pr-1)} - \frac{Gr}{Pr-1} \quad (18.6)$$

and

$$e = \frac{DfPrScGr}{(Sc-Pr)(Sc-1)} - \frac{Gm}{Sc-1} \quad (18.7)$$

In the Nomenclature Section, we have abbreviated the different constants used in the above Mathematical Analysis.

3. Results and Discussion

In Figure 1, for the values of Schmidt number (0.16, 0.3, 0.6), the effects of Concentration Profiles at time t = 0.2 are shown, which is vital in the field of concentration. It is noticed that the wall concentration raises with the reducing numbers of the Schmidt number (Sc), i.e., the ratio of mass diffusivity and kinematic viscosity.

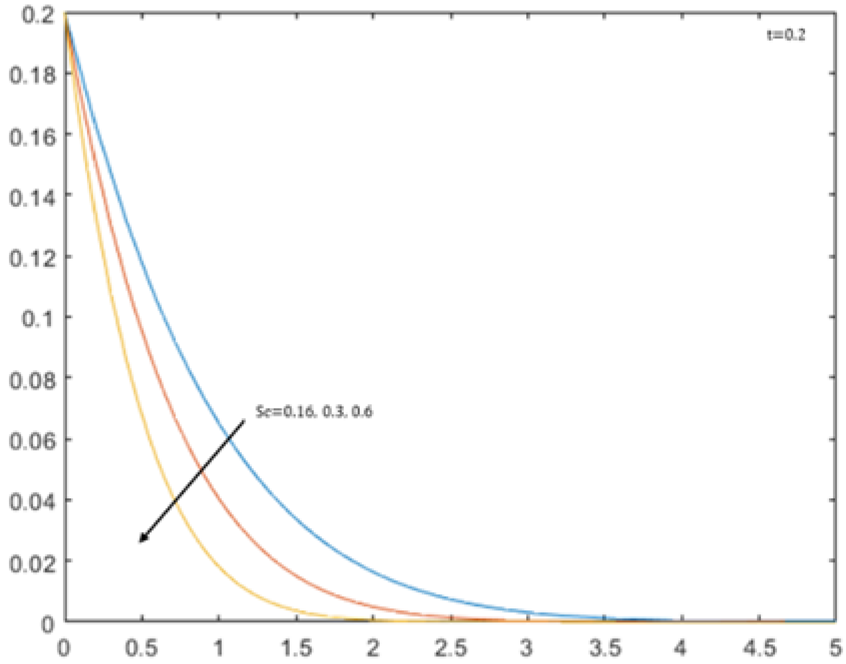

Figure 1. Concentration Profile for different values of Sc

Figure 2 represents the temperature profile which booms up the temperature with the rise in Dufour Number.

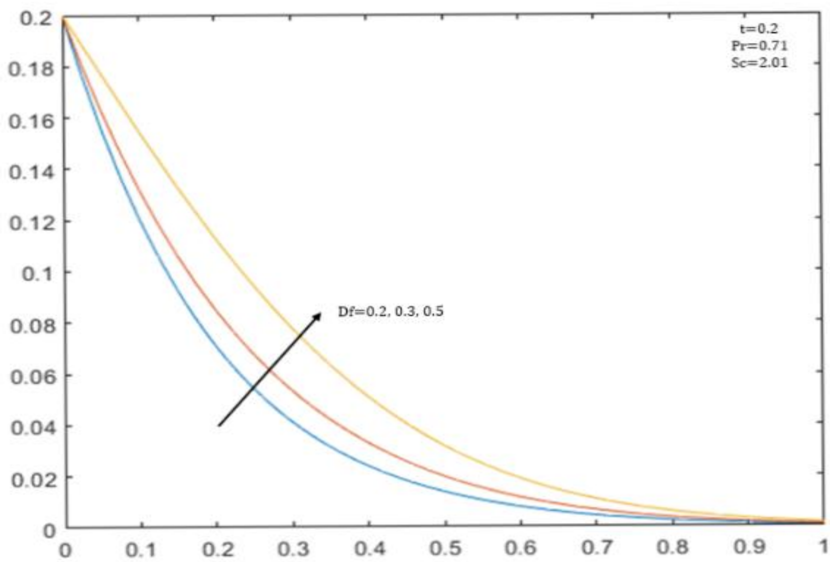

Figure 2. Temperature Profile for different values of Df

Figure 3 showed a decrease in temperature measurement as the Prandtl Number (Pr) went on a smooth increase.

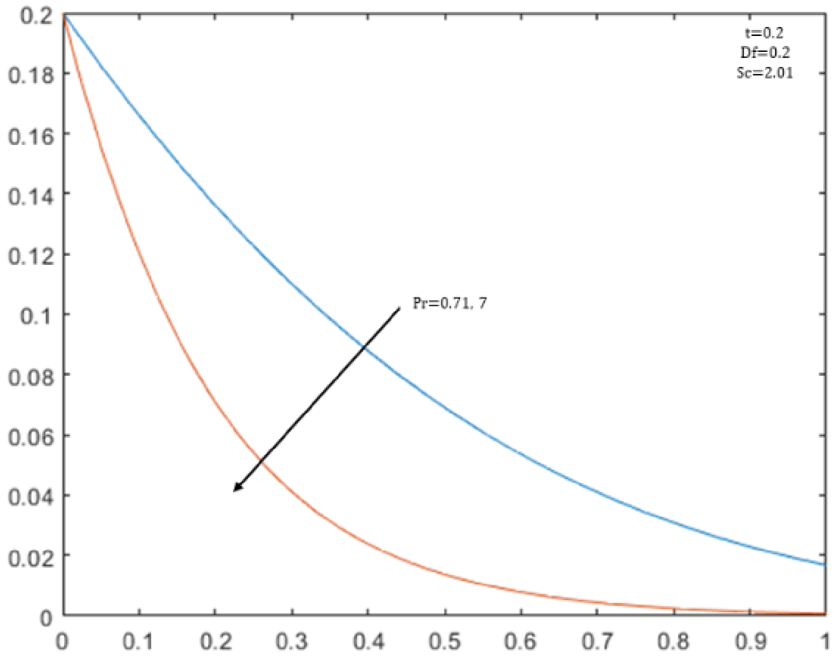

Figure 3. Temperature Profile for different values of Pr

Figure 4 showed up a temporary increase in temperature measurement. After some point, the temperature gradually dropped as the Schmidt Number (Sc) went on an increase.

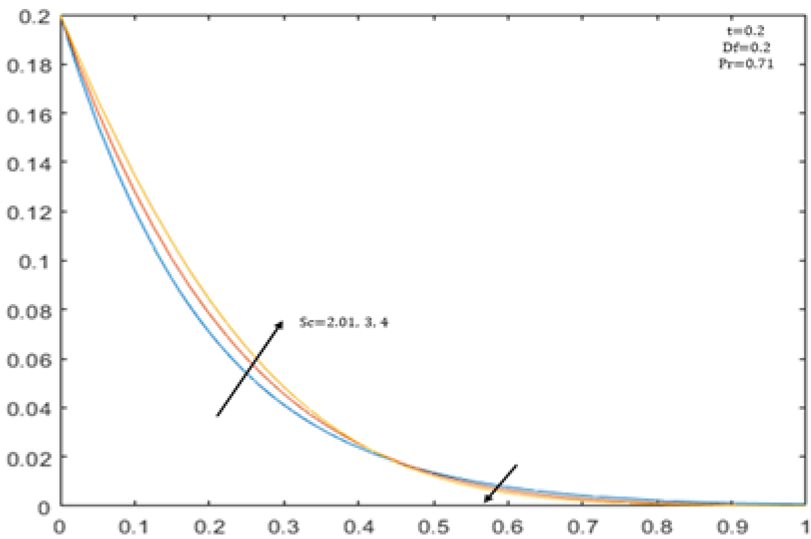

Figure 4. Temperature Profile for different values of Sc

Similarly, Figure 5, which also represents the Temperature profile, shows a considerable increase in time flow.

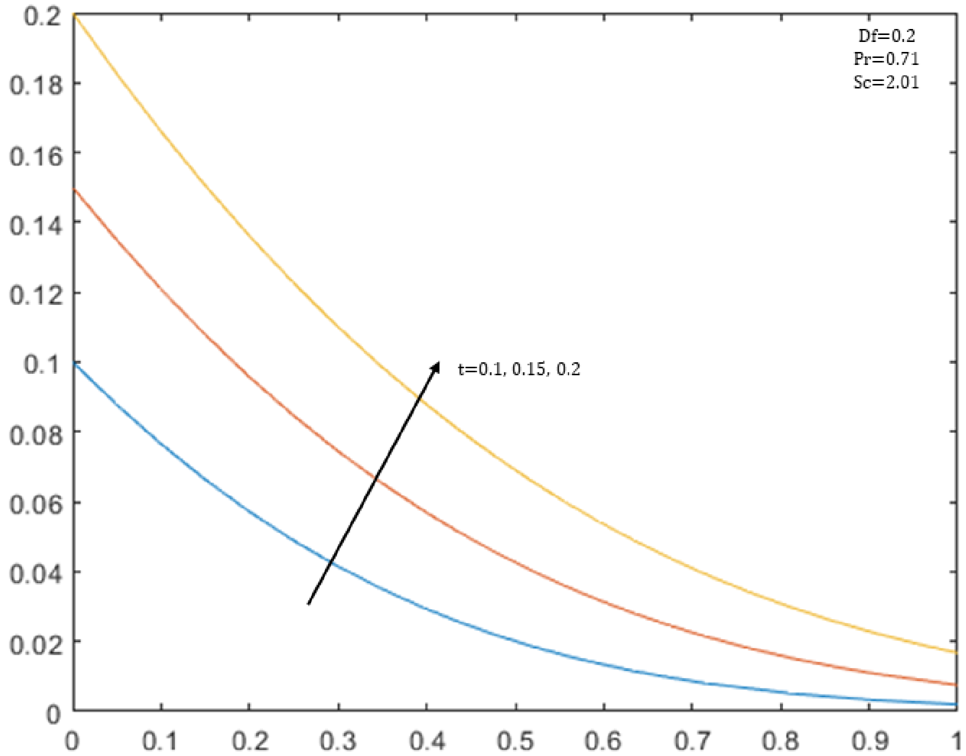

Figure 5. Temperature Profile for different values of t

Figure 6 showed a decline in velocity, accompanied by a large bloom in the hall parameter (m).Figure 7 showed up a slight increase in velocity with a considerable upsurge in the Dufour (Df) parameter. Figure 8 also shows an increase in the velocity with an upsurge in the Mass Grashof Number (Gm) parameter.Figure 9 showed an intensification in velocity with a considerable increase in the Thermal Grashof Number (Gr) and time (t) parameters.Figure 10 also has a fall in the velocity as there is an increment in the value of the Magnetic Field Parameter (M). Figure 11 portrays a reduction with velocity, followed by considerable growth in the Prandtl Number (Pr). Figure 12 also comes up with a decrease in velocity as there is a considerable increase in Schmidt Number.Figure 13 also comes up with an intensified (boosted) velocity with a gradual flow (increase) of time (t) parameter where Figure 9 and Figure 13 showed an intensification in velocity with a considerable increase in the Thermal Grashof Number (Gr) and time (t) parameters.

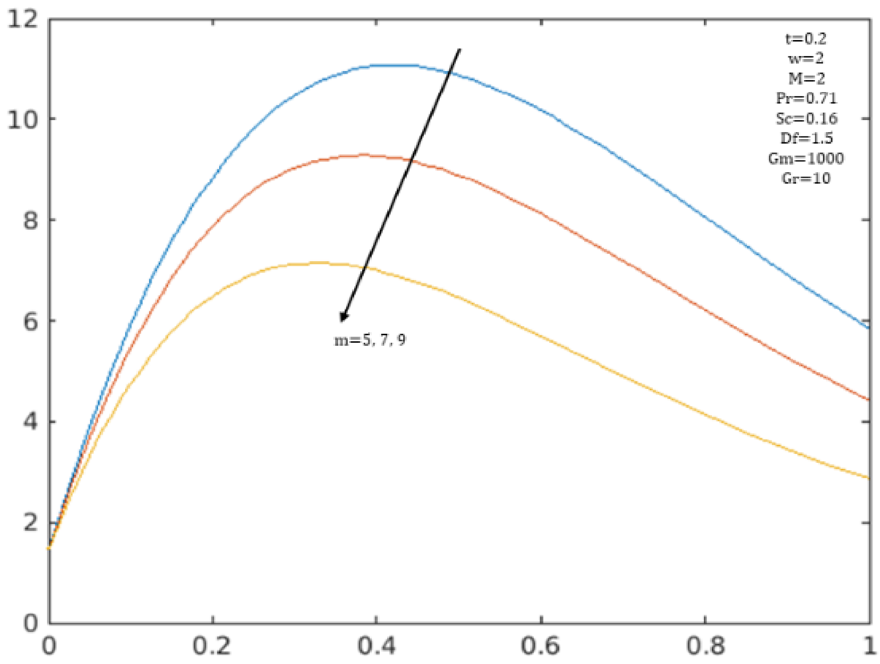

Figure 6. Velocity Profile for different values of m

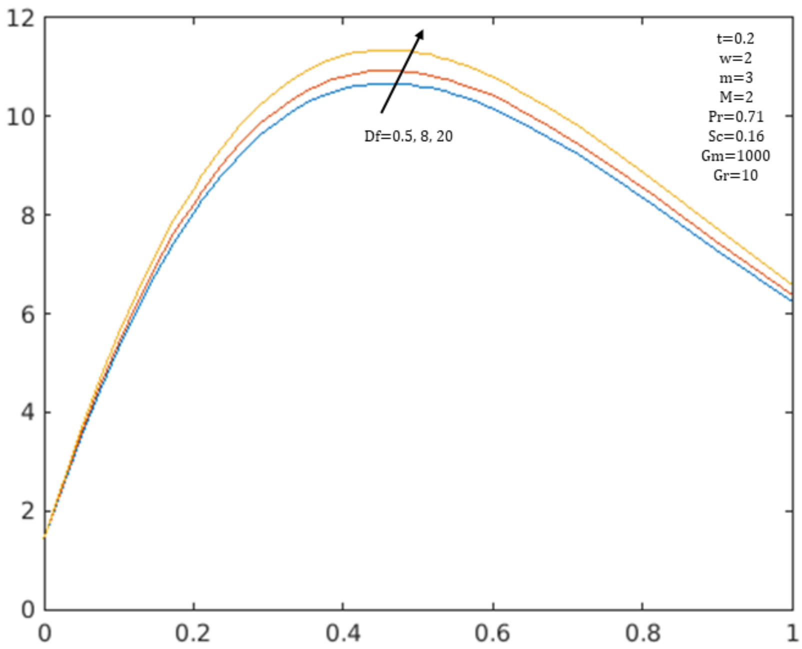

Figure 7. Velocity Profile for different values of Df

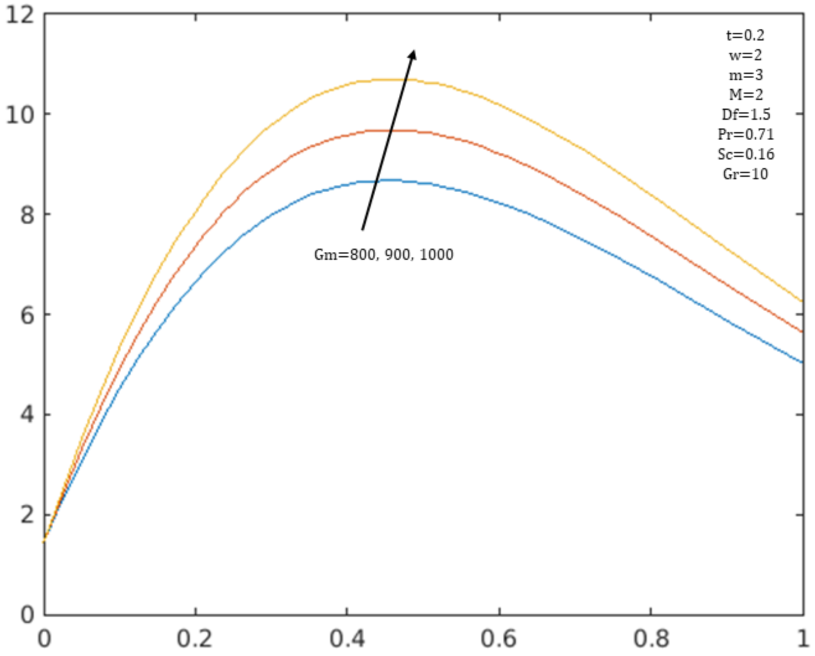

Figure 8. Velocity Profile for different values of Gm

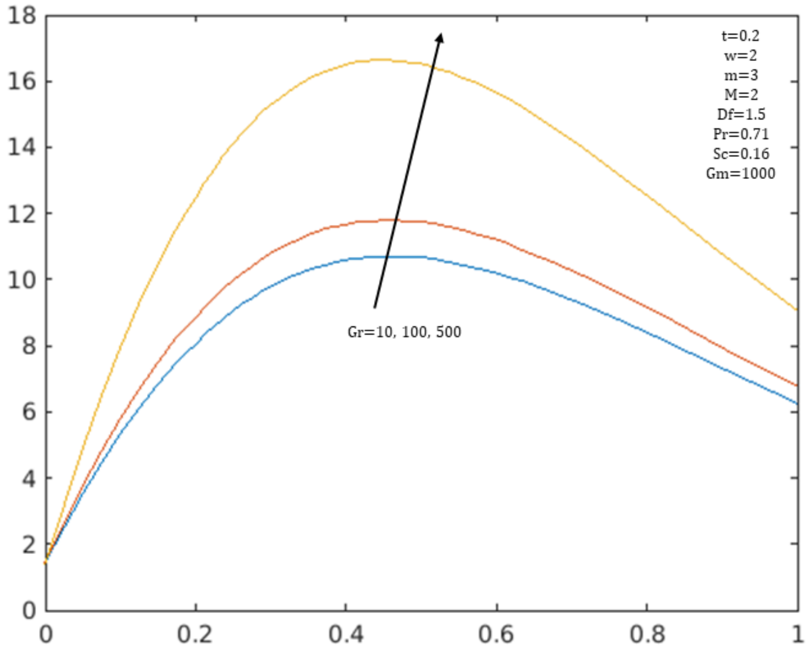

Figure 9. Velocity Profile for different values of Gr

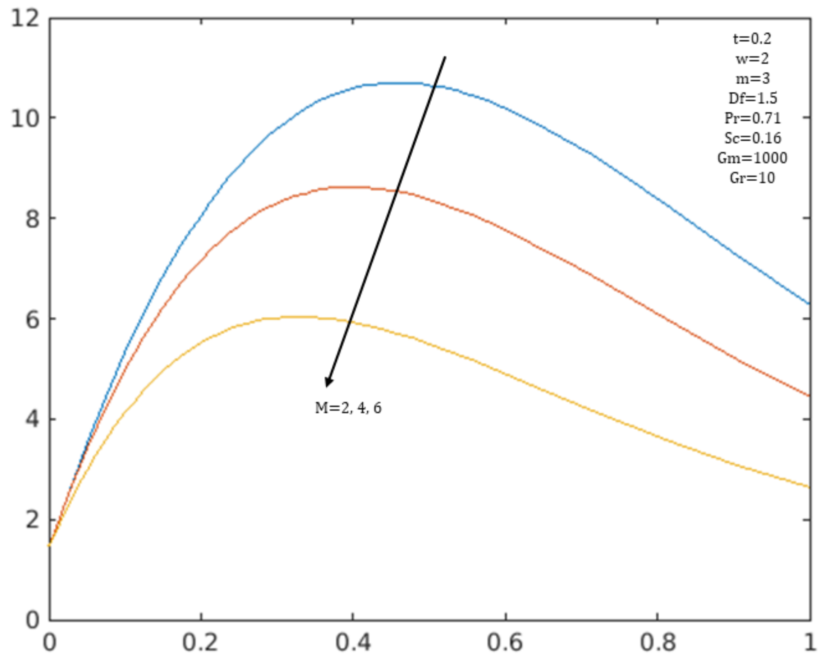

Figure 10. Velocity Profile for different values of M

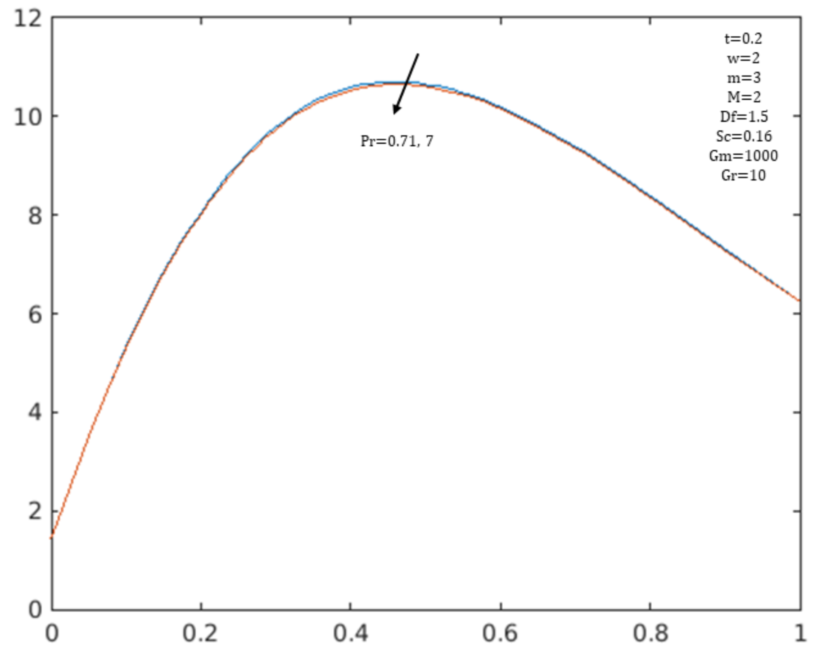

Figure 11. Velocity Profile for different values of Pr

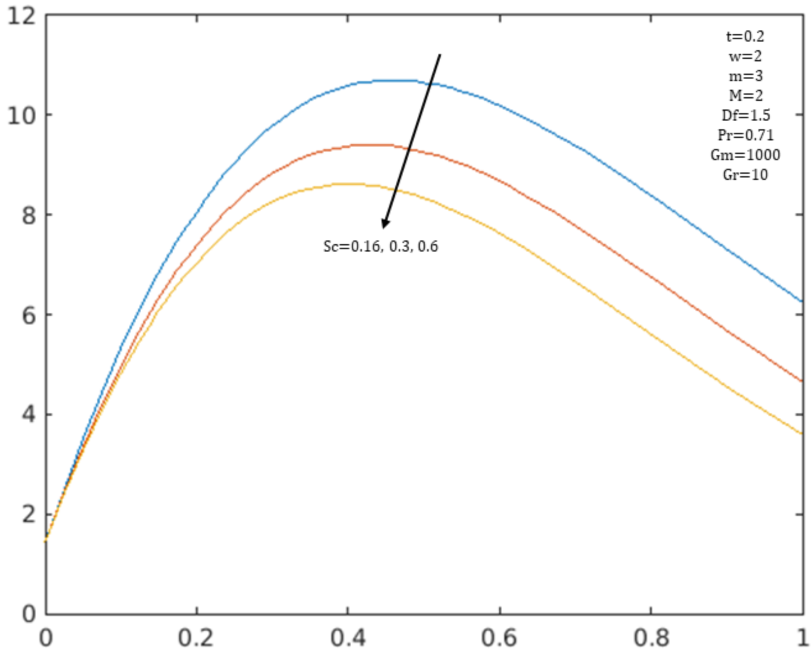

Figure 12. Velocity Profile for different values of Sc

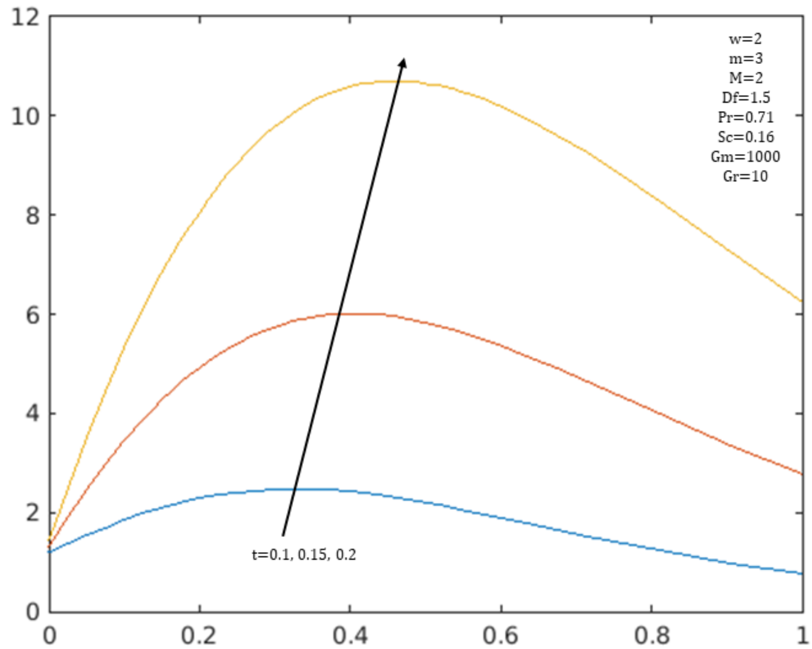

Figure 13. Velocity Profile for different values of t

In Figure 14, for the values of time (0.1, 0.15, 0.2), the effects of Concentration Profiles when Sc = 2.01 are shown. It is noticed that the wall concentration is raised with the raising value of time. Figure 2 represents the temperature profile which booms up the temperature with the rise in Dufour Number.

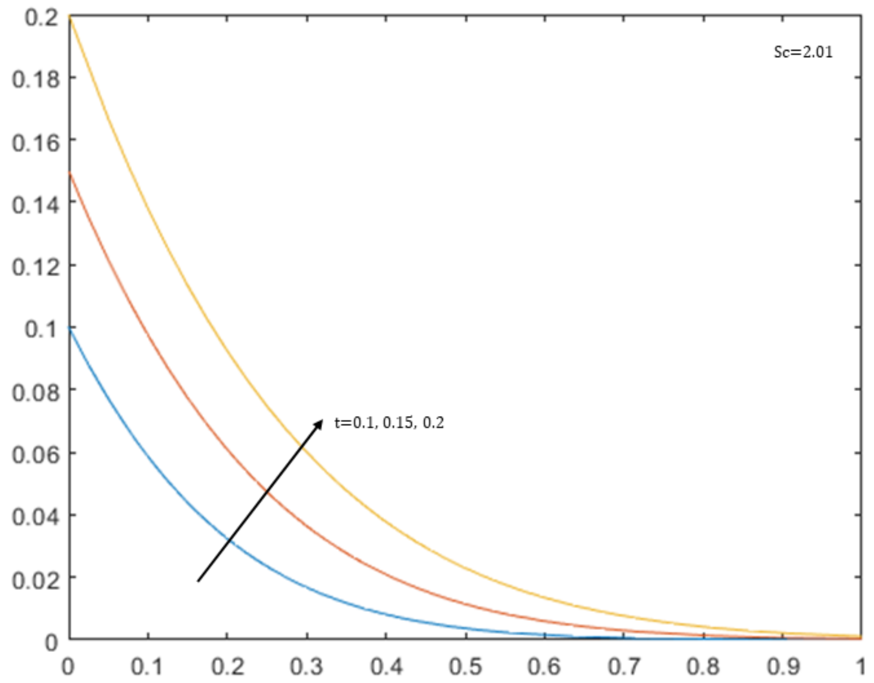

Figure 14. Concentration Profile for different values of t

4. Conclusion

The cause of Dufour and Hall's combined effect on Magnetohydrodynamic flow past an exponentially accelerated vertical plate with varying temperature and varying mass diffusion is revealed Graphically and Mathematically. The Mathematical equations for this model have been acquired by utilising Laplace Transform Technique. The Dynamic Effects of Dufour Number, Grashof Number, Hall Parameter, Hartman Number, Schmidt Number, Prandtl number, and time are presented graphically with MATLAB contribution. The solutions obtained to calculate the potential of concentration, temperature and velocity with Dufour and Hall effects are abbreviated below.

A temporary increase in temperature is showed up first. After some point, the temperature is gradually dropped as the Schmidt Number (Sc) increases. The fluid showed up a gradual increase in speed with the rising values of Mass and Thermal Grashof Number, Time and Dufour Number. In contrast, this process involves a depression in velocity with the elevating values of Prandtl Number, Hall and Magnetic Parameter.

Nomenclature:

(u, v, w)	Components of velocity field Q
$(\bar{u}, \bar{v}, \bar{w})$	Non-Dimensional velocity components
(x, y, z)	Cartesian Co-ordinates

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$\rightarrow \infty$
T_w	The temperature of the plate at y$= 0$
C	Species concentration in the fluid
C_∞	Species concentration at y$\rightarrow \infty$
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
m	Hall parameter
M	Hartman 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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