MHD and Dufoureffect parabolic flow past an accelerated vertical plate with unform temperature and mass diffusion in the presence of rotation

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Abstract: Influence of Dufour on Instability The present research investigates the rotational impact on the magnetic parabolic flow through an accelerated vertical plate in a magnetic field when the temperature and the rate of mass diffusion remain constant. The fluid under consideration conducts electricity. The solutions for the profiles of velocity, temperature, and concentration have been found using the Laplace transform method. Discussion of the findings can be assisted by graphs generated for a variety of factors, including the thermal Grashof number, the mass Grashof number, the Prandtl number, the Hartmann number, the Schmidt number, the Dufour number, the time of the magnetic field, and the acceleration parameter. As the estimated heated Grashof number (or mass Grashof) rises, so does the velocity. It is also verified that a decrease in the magnetic field M results in an increase in velocity.

Keywords*: vertical plate, parabolic, magnetic field, mass diffusion, Rotation, Dufour effect*

1. Introduction

Since heat and mass transmission are so important to daily life, many scientists have been studying them for a long time. This field of study investigates the dynamics of moving fluids and the forces acting on them when they are still. This subject area also goes by the name of fluid mechanics. From the point of view of technology, the experimental and theoretical investigations of magnetohydrodynamic flows are significant because they have a wide range of applications, including magnetohydrodynamics, electrical power, the manufacturing process, geophysics, etc. In many applications, such as the moulding and extrusion of plastics in the production of rayon and nylon, the processing of magnetic materials, the manufacturing control procedures for glass, the paper industry in various geophysical cases, etc., the influence of a magnetic field on the viscous, incompressible flow of an electrically conducting fluid is significant. The manufacturing line's cooling of threads or sheets of particular polymer materials is crucial in several process sectors. Numerous industrial uses, such as the magnetic control of molten iron flow in the steel industry and liquid metal cooling in nuclear reactors, depend heavily on magnetoconvection

Soundalgekar et al. [13] investigated the MHD effects on an impulsively begun vertical infinite plate with changeable temperature in the presence of a transverse magnetic field. Soundalgekar et al. investigated the effects of a transversely applied magnetic field on the flow of an electrically conducting fluid through an impulsively begun infinite isothermal vertical plate. [14] Using the Laplace transform approach; the dimensionless governing equations were solved. Soundalgekar and Takhar [15] investigated the radiative free convection flow of an optically thin gray-gas across a semi-infinite vertical plate. Hossain and Takhar investigated the effects of radiation on mixed convection along an isothermal vertical plate [4]. Alam and Sattar [6] investigated the influence of thermal diffusion on MHD free convection and mass transfer flow.Alam et al. [5] investigated the impact of thermal-diffusion on impulsively begun vertical porous plates and unsteady MHD free convection and mass transfer flow. Basanth Kumar Jha and Ravindra Prasad [1] have presented a concise explanation of the effects of free convection and mass exchange on the stream passing past a quickly moving perpendicular plate containing heat sources. In the Stoke issue on a finite vertical plate, Basant Kumar J. H. A. and A. K. Singh [2] investigated the soret impact on free convection and mass transfer flow. Dilip Jose and Selvaraj [3] conducted a study on the rotational impacts of parabolic flow past in a vertical plate with chemical reactions and convective heat and mass transfer. Muthucumaraswamy et al. focused on the effects of rotation on the MHD stream of an accelerated isothermal perpendicular plate with heat and mass dispersion [7]. Muthucumaraswamy et al. focused on the rotational influence on the MHD stream past an accelerated perpendicular plate [8]. Selvaraj et al. [9] investigated MHD parabolic flow over an accelerating isothermal vertical plate with mass and heat diffusion while including rotation. The Rotational Effect of Unsteady MHD-Parabolic Flow Past a Vertical Plate in Porous Medium with Uniform Temperature Mass Diffusion is studied by Selvaraj et al. [10]. The Dufour and Hall Effects on MHD Flow Past an Exponentially Accelerated Vertical Plate were examined by S. Constance Angela and A. Selvaraj [11]. Dufour effect on unsteady free convection MHD flow through an exponentially accelerated plate via porous media was explored by U. S. Rajput and N. K. Gupta [12]. In this way, it is suggested that the rotational effects of parabolic flow past an impenetrable viscous and electrically coordinating fluid past a consistently quickened unbound isothermal vertical plate in the vicinity of heat and mass transfer in the presence of Dufour and of magnetohydrodynamics be analysed. Laplace transform methods are used to highlight the non-dimensional administration condition.

2. Mathematical Formulation

The flow of an unsteady, viscous, incompressible fluid has been taken into consideration in the present piece of work. The taken plate is not electrically conductible. The x-axis is taken vertically along the plate, and the y-axis is taken perpendicular to it. The plate is subjected to a constant magnetic field applied with rotation magnetic field $\boldsymbol{B_0}$. At first, the fluid and plate are both at the same temperature $\boldsymbol{T_\infty}$ and the fluid is $\boldsymbol{C_\infty}$ concentration. At time$t > 0$, the plate begins to move vertically in its own plane with velocity $\boldsymbol{u = u_0 t'^2}$, temperature of the plate is increased to $\boldsymbol{T'_w}$ and the fluid concentration is raised to $\boldsymbol{C}_w$

The governing equations under the usual Boussinesq's approximations are as follows

$$\frac{\partial u}{\partial t'} - 2\Omega' v = g\beta(T - T_\infty) + g\beta^*(C' - C'_\infty) + v\frac{\partial^2 u}{\partial z^2} - \frac{\sigma B_0^2}{\rho}u \tag{1}$$

$$\frac{\partial v}{\partial t'} + 2\Omega' u = \frac{\partial^2 v}{\partial z^2} - \frac{\sigma B_0^2}{\rho}v \tag{2}$$

$$\frac{\partial T}{\partial t} = \frac{k}{\rho Cp}\frac{\partial^2 T}{\partial y^2} + \frac{DmK_T}{CsCp}\frac{\partial^2 C}{\partial y^2} \tag{3}$$

$$\rho C_p \frac{\partial C'}{\partial t'} = D\frac{\partial^2 C'}{\partial z^2} \tag{4}$$

With the initial and boundary conditions:

$$u = 0, T = T_\infty, C' = C'_\infty, \text{ for all } y, t' \le 0$$

$$t' > 0: \; u = \boldsymbol{u_0 t'^2}, T = T'_\infty + (T'_w - T'_\infty)\, At', C' = C'_\infty + (C'_w - C'_\infty)At' \text{ at y=0}$$

$$u = 0, T \to T_\infty, \; C' \to C'_\infty \; \text{as} \; y \to \infty \quad (5)$$

Where $\boldsymbol{A} = \left(\frac{\boldsymbol{u_0^2}}{\boldsymbol{v}}\right)^{\mathbf{1/3}}$

On suggesting the subsequent dimensionless quantities

$$U = \frac{u}{(Vu_0)^{\frac{1}{3}}}, \; V = \frac{v}{(Vu_0)^{\frac{1}{3}}}, \; t = t'\left(\frac{u_0^2}{v}\right)^{\frac{1}{3}}, Z = z\left(\frac{u_0}{v^2}\right)^{\frac{1}{3}}$$

$$\theta = \frac{T - T_\infty}{T_w - T_\infty}, \; Gr = \frac{g\beta\,(T_w - T_\infty)}{u_0}, C = \frac{C' - C'_\infty}{C'_w - C'_\infty} \quad (6)$$

$$Gc = \frac{g\beta^*(C'_w - C'_\infty)}{u_0}, M = \frac{\sigma B_0^2}{\rho}\left(\frac{v}{u_0^2}\right)^{\frac{1}{3}}, pr = \frac{\mu C_p}{k}, sc = \frac{v}{D}$$

$$Df = \frac{DmK_T(C_w - C_\infty)}{\vartheta CsCp(T_w - T_\infty)}$$

Using (6) in the equation (1) to (4), we have derived

$$\frac{\partial U}{\partial t} - 2\Omega V = Gr\theta + GcC + \frac{\partial^2 U}{\partial Z^2} - MU \quad (7)$$

$$\frac{\partial V}{\partial t} + 2\Omega U = \frac{\partial^2 V}{\partial Z^2} - MV \quad (8)$$

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

$$\frac{\partial C}{\partial t} = \frac{1}{sc}\frac{\partial^2 C}{\partial Z^2} \quad (10)$$

with initial and boundary conditions are

$$u = 0, T = T_\infty, C' = C'_\infty \; for\ all\ y, t' \leq 0$$

$$t' > 0 \qquad u = \boldsymbol{u} = \boldsymbol{u_0 t'^2}, T = T_w, C' = C'_w \; at\ y = 0 \quad (11)$$

$$u \to 0, T \to T_\infty, C' \to C'_\infty \; at\ y \to \infty$$

Now the set of equations (7) and (8) with the boundary condition (11) we present a complex velocity $q = u + iv$ then into single equation.

$$\frac{\partial q}{\partial t} = \mathrm{Gr}\theta + \mathrm{Gc}C + \frac{\partial^2 q}{\partial Z^2} - mq \quad (12)$$

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

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

The starting and limit conditions using non-dimension quantities are as follows

$$q = 0, \quad \theta = 0, \quad C = 0 \quad for\ all\ Z, t \le 0$$

t> 0 $\quad q = t^2, \quad \theta = 1, \quad C = 1 \quad Z = 0$ (15)

$$q \to 0, \quad \theta \to 0, \quad C \to 0 \quad Z \to 0$$

where m=M+2iΩ

3. Solution of the problem

Laplace transforms are used to solve (12), (13), and (14) equations, which have a dimensionless administering condition and an associated beginning and limit condition. A final inverse transform is done, and the solutions are determined in the following manner

$$q =$$

$$\frac{(\eta^2+mt)t}{4m}\Big[\Big(e^{2\eta\sqrt{mt}}erfc(\eta+\sqrt{mt}) + e^{-2\eta\sqrt{mt}}erfc(\eta-\sqrt{mt})\Big) +$$

$$\frac{\eta\sqrt{t}(1-4mt)}{8m^{\frac{3}{2}}}\Big(e^{-2\eta\sqrt{mt}}erfc(\eta-\sqrt{mt}) - e^{2\eta\sqrt{mt}}erfc(\eta+\sqrt{mt})\Big) - \frac{\eta t}{2m\sqrt{\pi}}e^{-(\eta^2+mt)}\Big]$$

$$-\frac{Gr}{a(1-pr)}\Big[\frac{1}{2}\Big(e^{2\eta\sqrt{mt}}erfc(\eta+\sqrt{mt}) + e^{-2\eta\sqrt{mt}}erfc(\eta-\sqrt{mt})\Big) - erfc(\eta\sqrt{sc} \;-$$

$$\frac{e^{bt}}{2}\Big(e^{2\eta\sqrt{(m+b)t}}erfc\left(\eta+\sqrt{(m+b)t}\right) + e^{-2\eta\sqrt{(m+b)t}}erfc\left(\eta-\sqrt{(m+b)t}\right)\Big) +$$

$$\frac{e^{at}}{2}\Big(e^{2\eta\sqrt{prat}}erfc(\eta\sqrt{pr}+\sqrt{at}) + e^{-2\eta\sqrt{prat}}erfc(\eta\sqrt{pr}-\sqrt{at})\Big)\Big]$$

$$+\frac{Gc}{b(1-sc)}\Big[\frac{1}{2}\Big(e^{2\eta\sqrt{mt}}erfc(\eta+\sqrt{mt}) + e^{-2\eta\sqrt{mt}}erfc(\eta-\sqrt{mt})\Big) - erfc(\eta\sqrt{sc} \;-$$

$$\frac{e^{bt}}{2}\Big(e^{2\eta\sqrt{(m+b)t}}erfc\left(\eta+\sqrt{(m+b)t}\right) + e^{-2\eta\sqrt{(m+b)t}}erfc\left(\eta-\sqrt{(m+b)t}\right)\Big) +$$

$$\frac{e^{bt}}{2}\Big(e^{2\eta\sqrt{scbt}}erfc(\eta\sqrt{sc}+\sqrt{bt}) + e^{-2\eta\sqrt{scbt}}erfc(\eta\sqrt{sc}-\sqrt{bt})\Big)\Big]$$

$$-\frac{\mathrm{DfPrScGr}}{\mathrm{a(Sc-Pr)(Pr-1)}}\Big[\frac{1}{2}\Big(e^{-2\eta\sqrt{mt}}erfc(\eta-\sqrt{mt}) + e^{2\eta\sqrt{mt}}erfc(\eta+\sqrt{mt})\Big) - erfc(\eta\sqrt{pr}) -$$

$$\frac{e^{at}}{2}\Big(e^{2\eta\sqrt{(m+\mathrm{a})t}}erfc\left(\eta+\sqrt{(m+\mathrm{a})t}\right) + e^{-2\eta\sqrt{(m+\mathrm{a})t}}erfc\left(\eta-\sqrt{(m+\mathrm{a})t}\right)\Big) +$$

$$\frac{e^{at}}{2}\Big(e^{2\eta\sqrt{prat}}erfc(\eta\sqrt{pr}+\sqrt{at}) + e^{-2\eta\sqrt{prat}}erfc(\eta\sqrt{pr}-\sqrt{at})\Big)\Big]$$

$$-\frac{\mathrm{DfPrScGr}}{(\mathrm{Sc}-\mathrm{Pr})(\mathrm{Pr}-1)\mathrm{b}}\Big[erfc(\eta\sqrt{sc}\ -\frac{1}{2}\Big(e^{2\eta\sqrt{mt}}\ erfc\big(\eta+\sqrt{mt}\big)+e^{-2\eta\sqrt{mt}}erfc\big(\eta-\sqrt{mt}\big)\Big)\ -\frac{e^{bt}}{2}\Big(e^{2\eta\sqrt{scbt}}erfc\Big(\eta+\sqrt{(Scb)t}\Big)+e^{-2\eta\sqrt{scbt}}erfc\Big(\eta-\sqrt{(Scb)t}\Big)\Big)+\frac{e^{bt}}{2}\Big(e^{2\eta\sqrt{(m+b)t}}erfc\Big(\eta+\sqrt{(m+b)t}\Big)+e^{-2\eta\sqrt{(m+b)t}}erfc\Big(\eta-\sqrt{(m+b)t}\Big)\Big)\Big] \quad (16)$$

$$C = erfc(\eta\sqrt{sc}) \quad (17)$$

$$\theta = erfc\big(\eta\sqrt{Pr}\big)+\frac{DfPrSc}{Sc-Pr}\ \big[erfc\big(\eta\sqrt{Pr}\big)-erfc\big(\eta\sqrt{Sc}\big)\big] \quad (18)$$

$$erfc(a+ib) = \mathrm{erf}(a)+\frac{\exp(-a^2)}{2a\pi}[1-\cos(2ab)+isin(2ab)] + \frac{2\exp(-a^2)}{\pi}\sum_{n=1}^{\infty}\frac{\exp(-\eta^2/4)}{\eta^2+4a^2}[f_n(a,b)+ig_n(a,b)]+\in(a,b)$$

Where $\boldsymbol{a}=\frac{\boldsymbol{m}}{\boldsymbol{pr-1}}, \boldsymbol{b}=\frac{\boldsymbol{m}}{\boldsymbol{sc-1}}\ \boldsymbol{and}\ \boldsymbol{\eta}=\frac{\boldsymbol{Z}}{\boldsymbol{2\sqrt{t}}}$

f_n = 2a-2a cosh(nb) cos (2ab) + n sinh (nb) sin (2ab)

and g_n=2a cosh(nb) sin (2ab) + n sinh (nb) cos (2ab)

$$|\epsilon(a,b)| \approx\approx 10^{-16}|erf(a+ib)|$$

4. Results and discussions

Numerical simulations are made for various physical parameters Du, M, t, Sc, and Gr, Gc, depending on the nature of the flow and transport, in order to interpret the findings for a better understanding of the issue. The Prandtl number Pr is selected to have a value of 0.71, which is representative of air. For the aforementioned parameters, the numerical values of the velocity, temperature, and concentration are calculated.

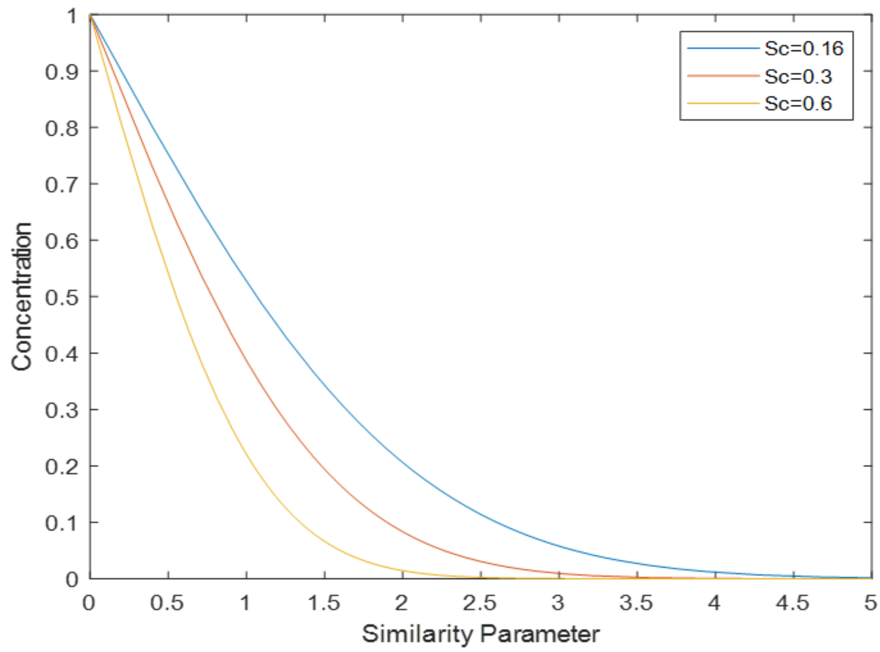

Fig.1 Concentration Profile for Various Value of Sc

The concentration scheme for period 0.2 is shown in Fig. 1, which is reasonable given that the various Schmidt values are 0.16, 0.3, and 0.6, respectively. It can be observed that the wall concentration grew with decreasing Schmidt value predictions as the wall concentration increased.

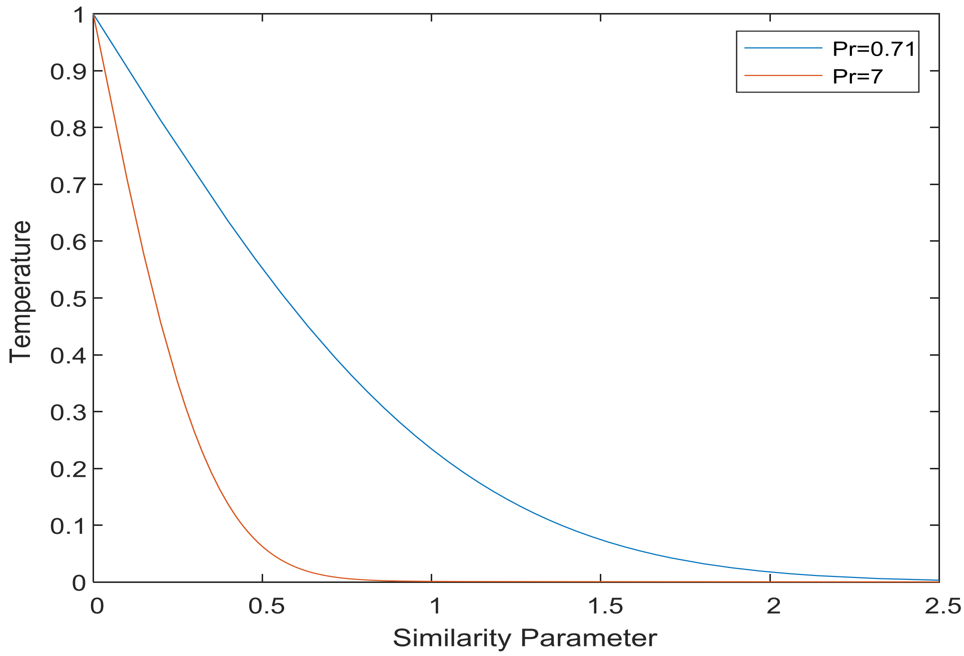

Fig .2 Temperature Trend for different values of Pr

The Schmidt Number Sc = 2.01 and the Dufour Number Df = 1.5 describe the temperature behaviour at time t =1 for Prandtl Number Pr =0.71 and Prandtl Number Pr =7, respectively. Air has a Prandtl number of 0.71 when compared to water. The combined influence of Dufour and Hall on temperature has an effect on fluid flows in air and water, causing the temperature of the fluid flow in air to be higher than that of the fluid flow in water. Prandtl number (Pr) increases are connected with a drop in temperatureas shown in fig.2

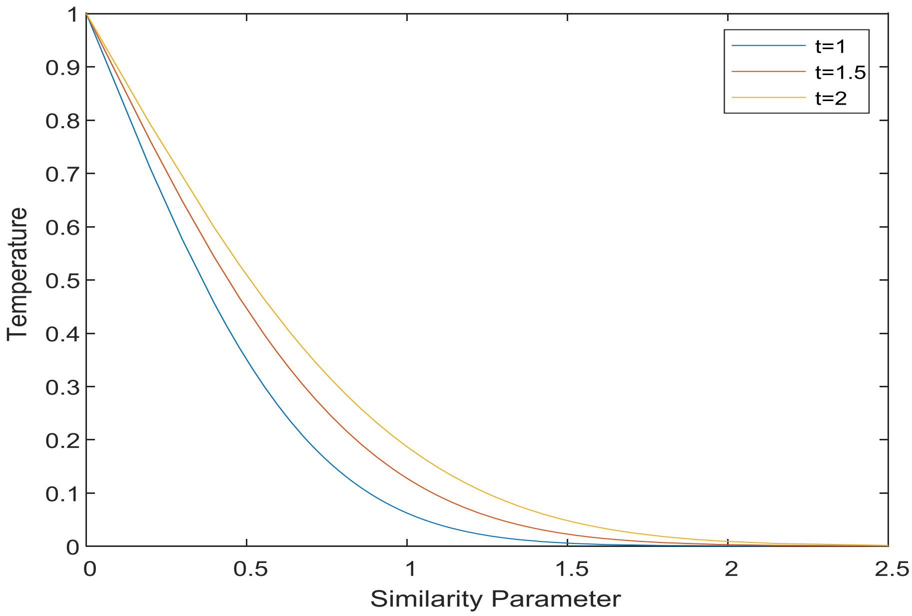

Fig.3 Temperature profile for different values of t

The temperature's behaviour is shown in Fig. 3 for the values of time t = 1, 1.5, 2, and 3. We may interpret the data using the Dufour, Prandtl, and Schmidt values as well as the temperature information. The fluid's reaction to a rise in temperature became more clear as time went on. The rising estimate of time causes the temperature to increase.

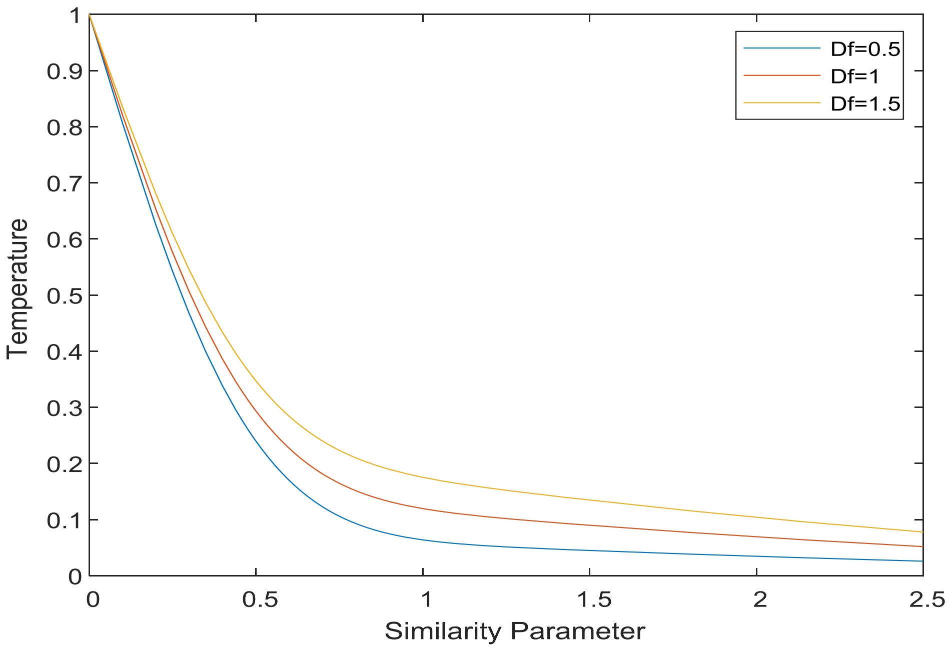

Fig.4 Temperature Trend for different values of Df

We may investigate the temperature's behaviour in further detail using the Dufour numbers Df = 0.15-0.23, the Schmidt number Sc = 2.01, the Prandtl number Pr 0.71, and t = 1 in Figure 6.4. When a number of irreversible processes interact to produce a mass concentration gradient, this is known as the Dufour effect. In general, as the Dufour number (Df) grows, so does the temperature.

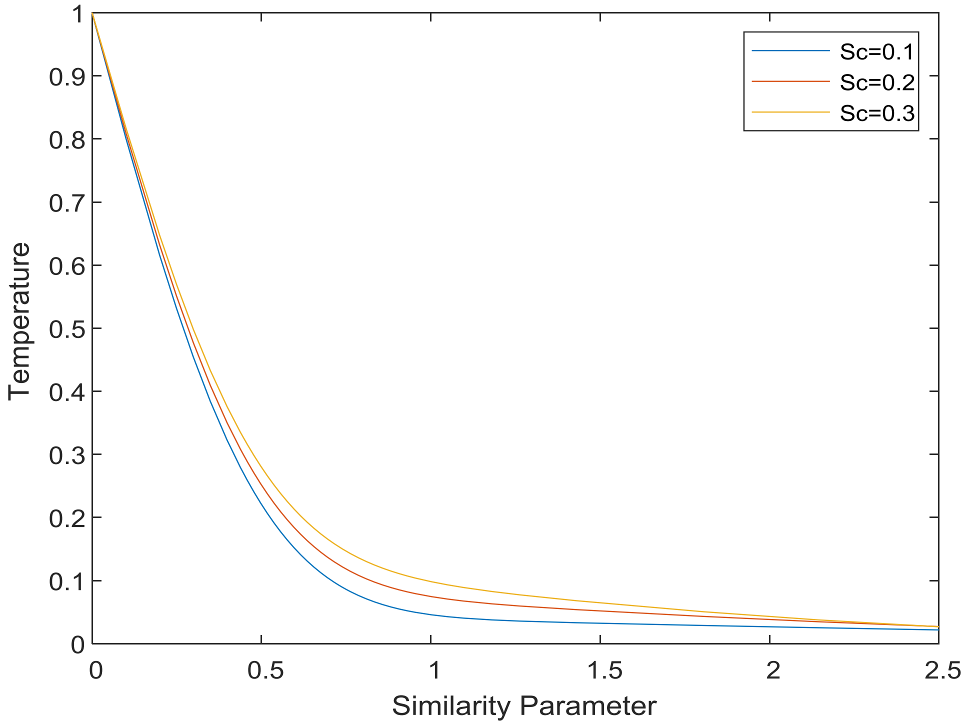

Fig.5 Temperature profile for different values of Sc

The temperature behaviour is shown in Fig. 5 for the values of the Schmidt number Sc = 0.1, 0.2, and 0.3, the Prandtl number Pr = 0.71, the Dufour number Df = 0.5, and the time t = 0.2. When the combined effects of Dufour and Hall are present, the Schmidt number (Sc) rises, suggesting a propensity for the temperature to rise. The temperature then swings, and it becomes evident that the trend has changed, resulting in a decrease in temperature overall at this point.

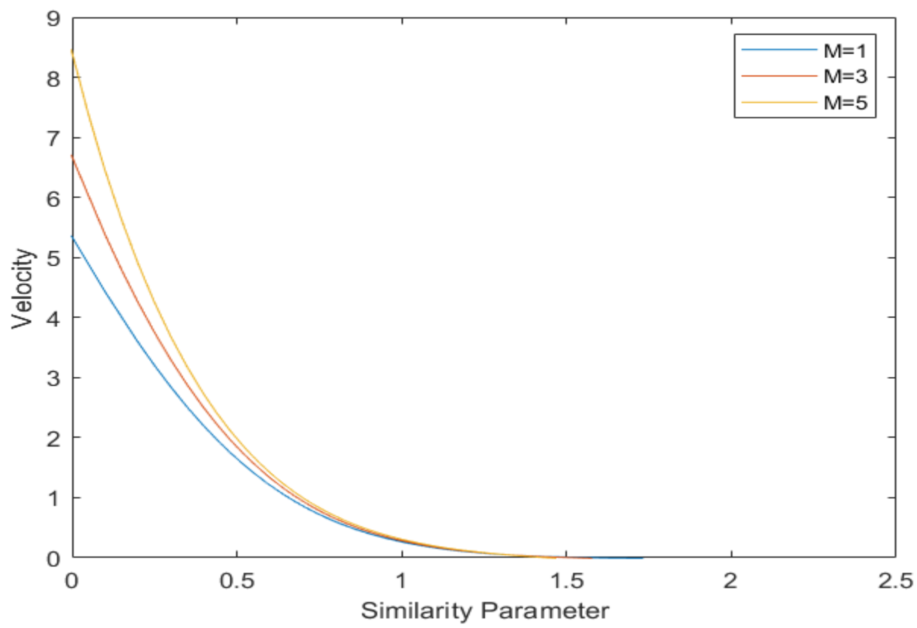

Fig.6 Velocity profile for different values of M

Fig. 6. showsthe velocity of the plate for different magnetic field parameter numbers (M=1,3,5)and produce the highest velocity with increase the magnetic number.

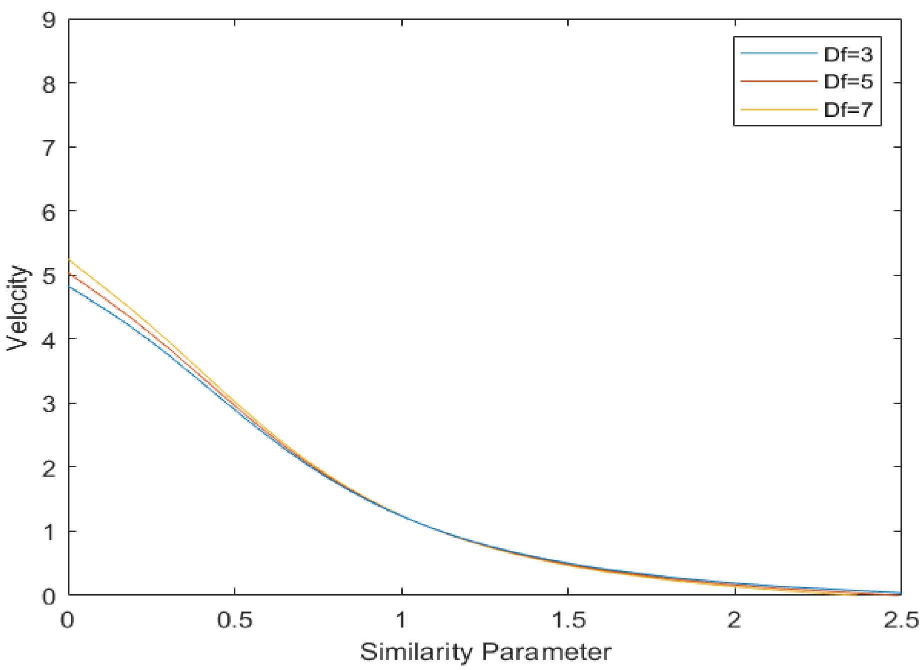

Fig.7 Velocity profile for different values of Df

Fig.7. shows the velocity of the plate for different Dufour numbers (Df=3,5,7) and produce the highest velocity with increase the Dufour number.

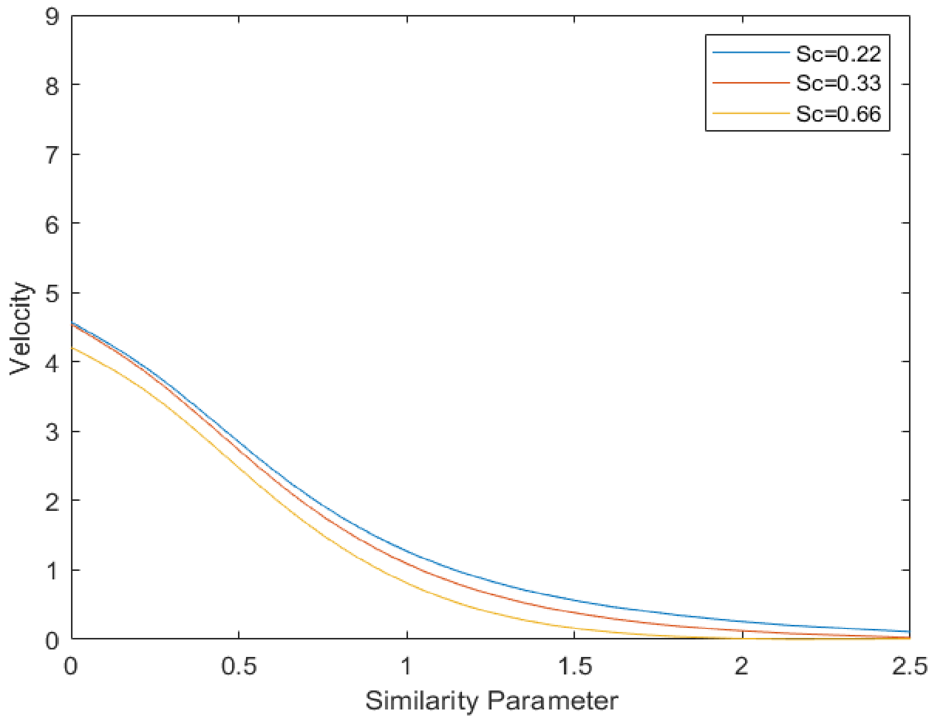

Fig.8 Velocity profile for different values of Sc

Fig.8 shows the velocity outlines of the plate at various Schmidt values (S_c = 0.22,0.33,0.66). The Schmidt number for a plate decreases as its velocity increases

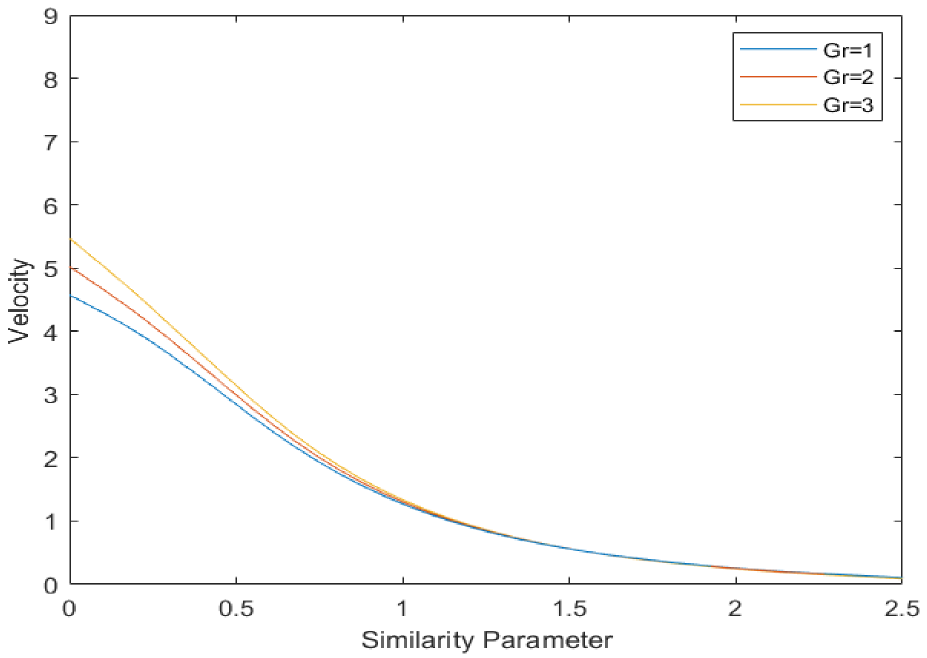

Fig.9 Velocity profile for different values of Gr

The diagram above shows the velocity outlines of the plate at various values of Gr =1,2,3. The Gr values increases as its velocity increases

5. Conclusion

The exact act of the combination of the Dufour Effects with rotational on Magnetohydrodynamic Flow past an Isothermal Vertical Plate, which is parabolic accelerated with uniform temperature and mass dissemination, is observed and investigated in this document. In order to decode the fundamental flow mathematical statements, the techniques found in Laplace transforms are utilised, and a better understanding of the equations is gained. Graphs, which are an efficient technique of showing data and demonstrating its difference, are utilised to help expose all of the repercussions, which may be shown to be the result ofAccording to the findings of the research, the Temperature, Concentration, and Velocity Sketches of the Schemes Are as Follows:

- When there is an increase in time, the graph shows that the wall thickness increases, and vice versa for the Schmidt number.
- When the values of Df, Sc, and t are increased, there is a corresponding rise in the temperature sketches. In contrast, for the Prandtl number, there is a fluctuation in temperature in both the air and the water medium. This is the case throughout the experiment.
- The velocity tends to decrease gradually for the parameters Prandtl Number, Schmidt Number and Magnetic field parameter Number, Dufour number However, the graph shows a decent increase in velocity for the parameters Mass Grashof Number, Thermal Grashof Number, and time.

List of nomenclature

C'	- Species concentration in the fluid
C	- Dimensionless Concentration
C'w	- Wall Concentration
C∞	- Concentration far away from the plate
Cp	- Specific Heat at Constant Pressure
D	- Mass Diffusion Coefficient
Gc	- Mass Grashofnumber
Gr	- Thermal Grashofnumber
G	- Accelerated due to gravity
Pr	- Prandtl Number
Sc	- Schmidt Number
T	- Temperature of the fluid near the plate
Tw	- Temperature of the plate
T∞	- Temperature of the fluid far away from the plate
t'	- Time
t	- Dimensionless Time

u	-	Velocity of the fluid in the x-direction
U_0	-	Velocity of the plate
q	-	Dimensionless Velocity
x	-	Spatial coordinate along the plate
y	-	Coordinate axis normal to the plate
Z	-	Dimensionless coordinate axis normal to the plate
β	-	Volumetric coefficient of thermal expansion
β*	-	Volumetric Coefficient of Expansion with Concentration
μ	-	Coefficient of Viscosity
υ	-	Kinematic Viscosity
ρ	-	The density of The Fluid
τ	-	Dimensionless Skin-Friction Kg
θ	-	Dimensionless Temperature
η	-	Similarity Parameter
erfc	-	Complementary Error Function
Du	-	Dufour number

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