Analysis on Soretand MHD effect of parabolic flow past an accelerated vertical plate with constant heat and mass diffusion in the presence of rotation

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Abstract: Soret impact of rotational action on the unsteady MHD parabolic flow across an accelerating vertical plate with constant mass diffusion and uniform temperature. The fluid under consideration conducts electricity. The solutions for the profiles of velocity, temperature, and concentration have been found using the Laplace transform method. Various graphs for parameters such as the thermal Grashof number, the mass Grashof number, the Prandtl number, the Hartmann number, the Schmidt number, the Soret number, the time of magnetic field, and the acceleration parameter are used to describe the findings obtained. The velocity is expected to expand as the mass Grashof or heated Grashof number is estimated to grow. It is also verified that the velocity increases as the magnetic field strength decreases.

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

1. Introduction

The study of magnetic field on viscous incompressible flow of electrically conducting fluid has stimulated the interest of many researchers because of its wide applications in various fields. MHD (Magneto hydrodynamics) plays an important role in agriculture, petroleum industries, geophysics and in astrophysics. MHD is the discipline that deals with the motion of electrically conducting fluids in presence of magnetic field. It concerns with the investigation of the interaction of magnetic fields and electrically conducting fluids (e.g., plasma, electrolytes, liquid metals etc.)

The process of mass transfer that occurs by the combine effects of concentration as well as temperature gradients is known as thermal diffusion or Soret effect. The experimental investigation of the thermal diffusion effect on mass transfer related problems was first performed by Charles Soret in 1879. Unsteady MHD free convective mass transfer flow past an infinite vertical porous plate with variable suction and Soret effect has been studied by Reddy et al. [7]. Hossain et al. [5] considered the study of unsteady MHD free convection flow past a vertical plate with thermal diffusion and chemical recation. Devi and Raj [3] investigated thermo diffusion effects on unsteady hydromagnetic free convection flow with heat and mass transfer past a moving vertical plate with time dependent suction and heat source in a slip flow regime. Mythreyeet al. [6] considered chemical reaction and Soret effect on MHD free convective flow past an infinite vertical porous plate with variable suction. The Soret effect on MHD free convective flow over a vertical plate with heat source was investigated by Bhavana et al. [2]. Very recently Ahmed et al. [1] studied the effects of heat and mass transfer in MHD free convective flow past a moving vertical plate with time dependent plate velocity in a porous medium.

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MHD effects on impulsively started vertical infinite plate with variable temperature in the presence of transverse magnetic field were studied by Soundalgekar et al. [15]. The effects of transversely applied magnetic field, on the flow of an electrically conducting fluid past an impulsively started infinite isothermal vertical plate were also studied by Soundalgekar et al. [16] the dimensionless governing equations were solved using Laplace transform technique.The radiative free convection flow of an optically thin gray-gas past semi-infinite vertical plate studied by Soundalgekar and Takhar[17].Basant Kumar J. H. A and A. K. Singh [2] studied on soret effect on free convection and mass transfer flow in the stoke problem for a finite vertical plate. Dilip Jose and Selvaraj [4] researched on convective heat and mass transfer on rotational effects of parabolic flow past in a vertical plate with chemical reaction.Impacts of Rotation on MHD stream a quickened isothermal perpendicular plate with warmth and mass dispersion was concentrated by Muthucumaraswamy.et.al [8]. Rotational impact on MHD stream past a quickened perpendicular plate was concentrated by Muthucumaraswamy.et.al [9]. MHD Parabolic flow across an accelerating isothermal vertical plate with mass as well as heat diffusion was studied by Selvaraj et al. [10] in the presence of rotation. Selvaraj et al. [11] analyse the Rotational effect of unsteady MHD-Parabolic Flow Past a Vertical Plate through porous medium with uniform temperature mass diffusion.S. Constance Angela and A. Selvaraj [12] analysed Dufour and Hall Effects on MHD Flow past an Exponentially Accelerated Vertical Plate. U. S. Rajput and N. K. Gupta [14] discussed about Dufour effect on unsteady free convection MHD flow past an exponentially accelerated plate through porous medium. The present work is concerned with the Soret effect on MHD convective heat and mass transfer flow of an unsteady viscous incompressible electrically conducting fluid past a vertical plate in presence of rotation.

2. Mathematical Formulation

In this paper we have considered the flow of unsteady viscous incompressible fluid. The plate taken is electrically non-conducting. The x- axis is taken along the plate in the upward direction and y- axis is taken normal to it. A uniform magnetic field $\boldsymbol{B_0}$ is applied on the plate with rotation. Initially the fluid and plate are at the same temperature $\boldsymbol{T_\infty}$ and the concentration of the fluid is $\boldsymbol{C_\infty}$. At time$t > 0$,
the plate starts moving vertically in its own plane with velocity $\boldsymbol{u = u_0 t'^2}$ temperature of the plate is raised to $\boldsymbol{T'_w}$and the concentration of the fluid is raised to C'_∞

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

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

$$\frac{\partial v'}{\partial t'} + 2\Omega' u' = \frac{\partial^2 v'}{\partial y'^2} - \frac{\sigma B_0^2}{\rho} v' \qquad (2)$$

$$\frac{\partial T}{\partial t'} = \frac{k}{\rho Cp} \frac{\partial^2 T}{\partial y'^2} \qquad (3)$$

$$\rho C_p \frac{\partial C'}{\partial t'} = Dm \frac{\partial^2 C'}{\partial y'^2} + \frac{Dm K_T}{T_m v} \frac{\partial^2 T}{\partial y'^2} \qquad (4)$$

With the initial and boundary conditions

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

$$t' > 0: \ u' = \boldsymbol{u_0 t'^2}, T' = T'_w, \ C' = C'_w \text{ at } y'=0$$

$$u' = 0, T' \to T'_\infty, \; C' \to C'_\infty \;\; \text{as} \;\; y' \to \infty \tag{5}$$

On suggesting the subsequent dimensionless quantities

$$U = \frac{u'}{u_0}, \; V = \frac{v'}{u_0}, t = \frac{t' u_0^2}{v}, \; y = y' \frac{u_0}{v}$$

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

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

$$C = \frac{v}{Dm}, \; Sr = \frac{DmK_T(T_w - T_\infty)}{T_m v(C_w - C_\infty)}$$

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

$$\frac{\partial U}{\partial t} - 2\Omega V = Gr\theta + GcC + \frac{\partial^2 U}{\partial y^2} - MU \tag{7}$$

$$\frac{\partial V}{\partial t} + 2\Omega U = \frac{\partial^2 V}{\partial y^2} - MV \tag{8}$$

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

$$\frac{\partial C}{\partial t} = \frac{1}{sc}\frac{\partial^2 C}{\partial y^2} + Sr\frac{\partial^2 \theta}{\partial y^2} \tag{10}$$

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.

$$\frac{\partial q'}{\partial t} = Gr\theta + GcC + \frac{\partial^2 q'}{\partial y^2} - mq' \tag{11}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{Pr}\frac{\partial^2 \theta}{\partial y^2} \tag{12}$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} + Sr\frac{\partial^2 \theta}{\partial y^2} \tag{13}$$

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

$$q' = 0, \quad \theta = 0, \quad C = 0 \quad for\ all\ y, t \leq 0$$

$$t > 0 \quad q' = t^2, \quad \theta = 1, \quad C = 1 \quad y = 0 \tag{14}$$

$$q' \to 0, \quad \theta \to 0, \quad C \to 0 \quad y \to 0$$

where m=M+2iΩ

3. Solution of the problem

Laplace transforms are used to solve (11), (12), and (13) 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

$$q' =$$

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

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

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

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

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

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

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

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

$$-\frac{\mathrm{SrPrScGr}}{\mathrm{a(Sc-Pr)(Pr-1)}}\Bigg[\frac{1}{2}\left(e^{-2\eta\sqrt{mt}}erfc\left(\eta-\sqrt{mt}\right)+e^{2\eta\sqrt{mt}}erfc\left(\eta+\sqrt{mt}\right)\right)-erfc(\eta\sqrt{pr})-$$

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

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

$$-\frac{\mathrm{SrPrScGr}}{\mathrm{(Sc-Pr)(Pr-1)b}}\Bigg[erfc(\eta\sqrt{sc}\ \ -\frac{1}{2}\left(e^{2\eta\sqrt{mt}}\ erfc\left(\eta+\sqrt{mt}\right)+e^{-2\eta\sqrt{mt}}erfc\left(\eta-\sqrt{mt}\right)\right)\ -$$

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

$$\left.\left.\sqrt{(m+b)t}\right)+e^{-2\eta\sqrt{(m+b)t}}erfc\left(\eta-\sqrt{(m+b)t}\right)\right)\Bigg] \quad (15)$$

$$\theta = erfc(\eta\sqrt{Pr}) \quad (16)$$

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

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

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

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

To interpret the results for a better understanding of the problem, numerical computations are carried out for different physical parameters Sr, M, t, Sc, and Gr, Gc, upon the nature of the flow and transport. The value of the Prandtl number Pr is chosen such that it represents air (Pr = 0.71). The numerical values of the velocity, temperature and concentration are computed for the above-mentioned parameters.

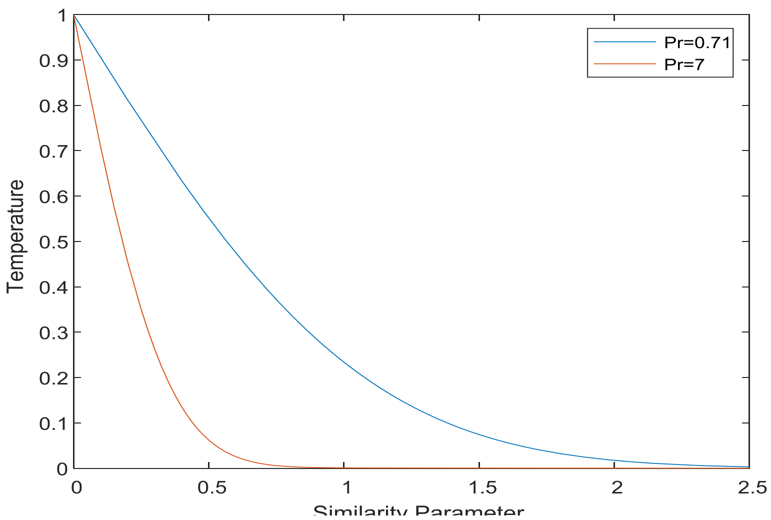

Fig .1 Temperature Trend for different values of Pr

For Prandtl Number Pr=0.71 and Prandtl Number Pr=7, respectively, the Schmidt Number Sc=2.01 and the Soret Number Df=1.5 explain the temperature behaviour at time t=1displayed in Figure 1 . In comparison to water, air has a Prandtl Number of 0.71. For fluid flows in air and water, the combined impact of Dufour and Hall has an effect on temperature that causes the temperature of the fluid flow in air to be greater than that in water. Increases in Prandtl Number (Pr) are associated with a decrease in temperature

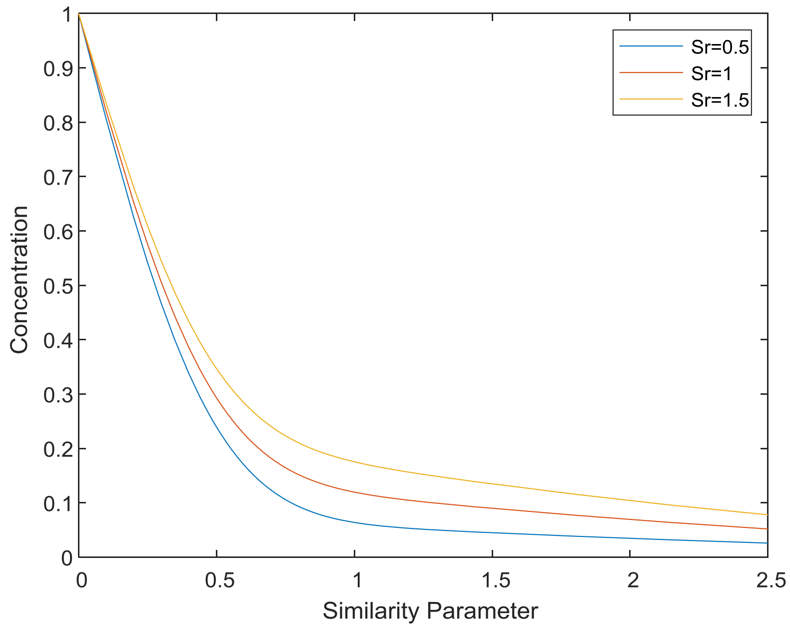

Fig.2 ConcentrationTrend for different values of Sr

With the SoretNumbersSr = 0.15-0.23, the Schmidt Number Sc = 2.01, the Prandtl Number Pr 0.71, as well as t = 1 in Figure 3, we may examine the temperature's behaviour in greater depth. It is known as the Soret effect when a mass concentration gradient results from a number of irreversible processes working together. In general, the temperature rises as the Soret Number (Sr) increases.

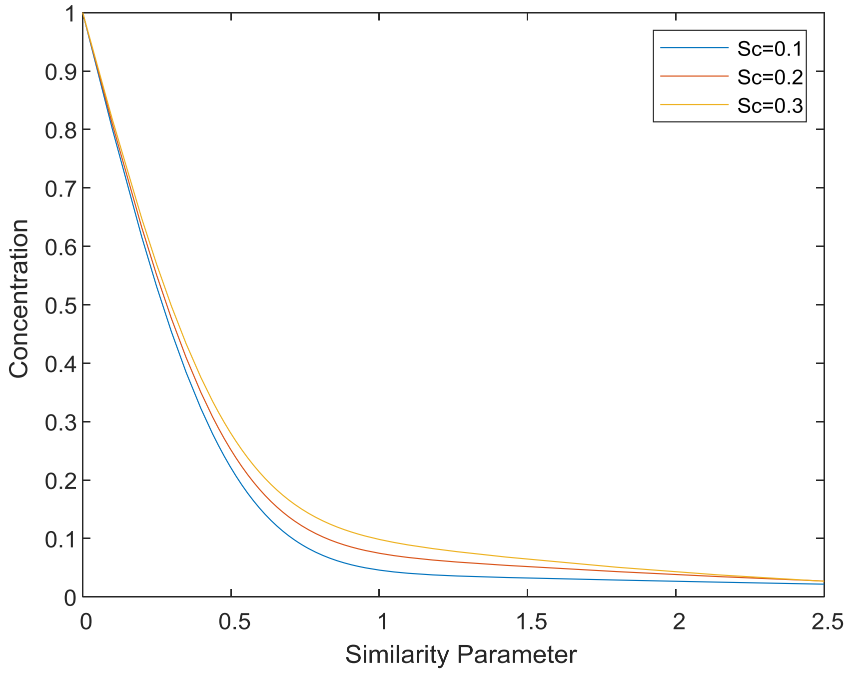

Fig.3 Concentrationprofile for different values of Sc

Fig.4 shows the temperature behaviour for the Schmidt Number Sc=0.1, 0.2, 0.3 and the Prandtl Number Pr= 0.71 ,Soret Number Sr=0.5 and Time t=0.2. The Schmidt Number (Sc) increases when the combined effects of Soret and Hall are present, indicating that the temperature has a tendency to rise. Next, the temperature fluctuates, and it's clear that the trend has reversed, leading to an overall reduction in temperature at point .

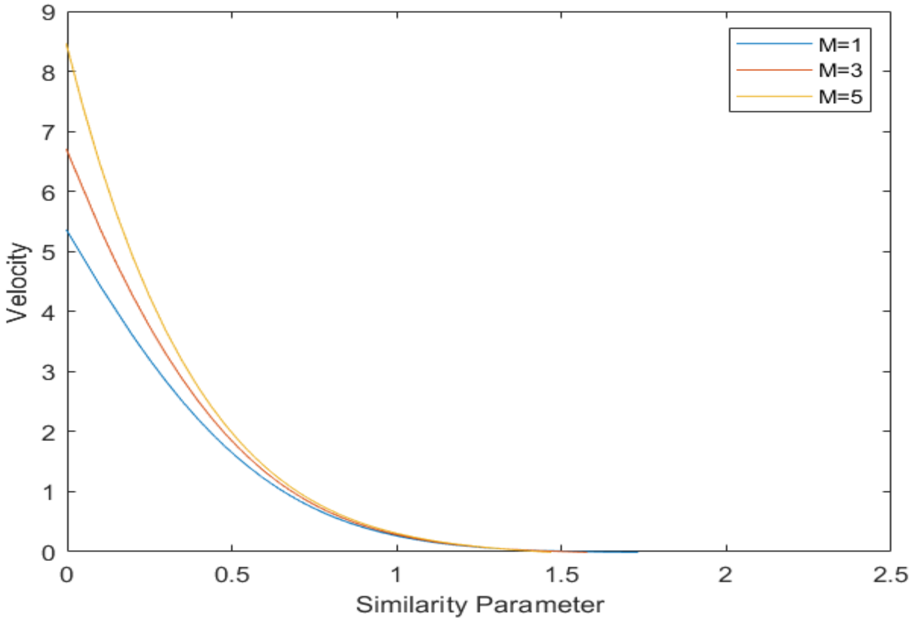

Fig.4 Velocity profile for different values of M

Fig.5. 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.

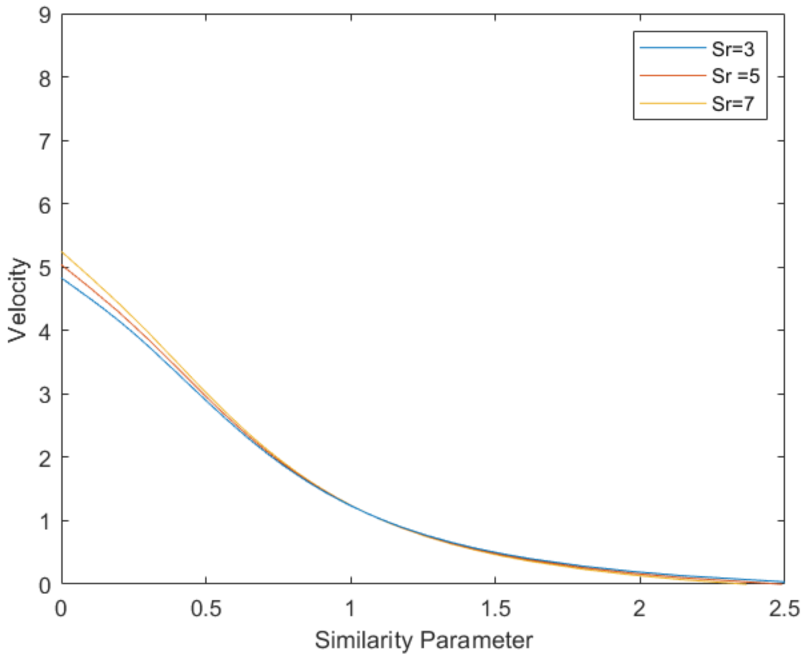

Fig.5 Velocity profile for different values of Sr

Fig.6. shows the velocity of the plate for different Soret numbers (Sr=3,5,7) and produce the highest velocity with increase the Dufour number.

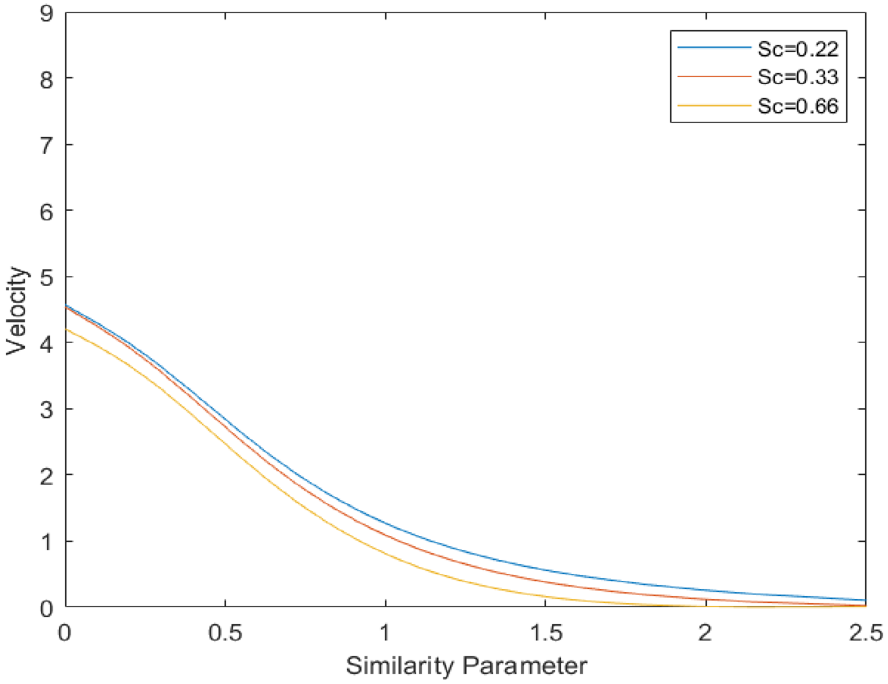

Fig.6 Velocity profile for different values of Sc

Fig.7shows 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

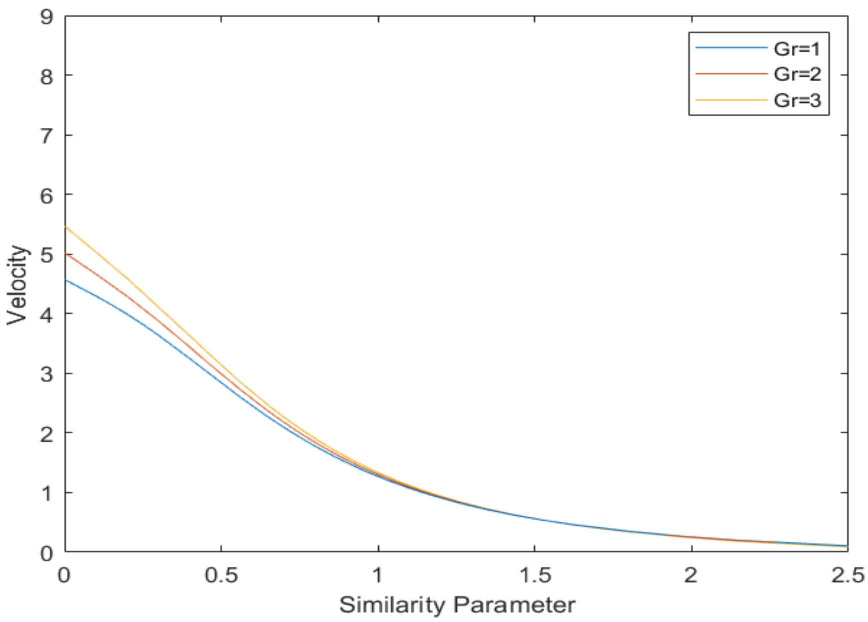

Fig.7 Velocity profile for different values of Gr

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

This work observes and investigates the exact method of the interaction of the Soret Effects with rotational on Magnetohydrodynamic Flow through an isothermal vertical plate that is parabolic accelerated with uniform temperature and mass distribution. The methods discovered in Laplace transforms are applied in order to decode the underlying flow mathematical assertions, and a deeper comprehension of the equations is obtained. Graphs are used to disclose all of the effects that may be proven to emerge from data, since they are an effective method of demonstrating information as well as proving its difference. The temperature, concentration, and velocity outlines of the schemes are as follows.

- The graph demonstrates that the wall thickness grows as time advances, and the Schmidt number does likewise.
- The temperature drawings grow in accordance with an increase in Sr, Sc, and t values. In contrast, there is a temperature variation for the Prandtl number in both the water and the air medium. This holds true for the duration of the experiment.
- For the parameters Prandtl Number, Schmidt Number, Magnetic field parameter Number, and Dufour Number, the velocity typically decreases gradually. The graph, however, indicates a reasonable rise in velocity for the variables time, thermal, and mass Grashof numbers.

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
Sr	-	Soret number

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