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RESEARCH ARTICLE

Rotation and Dufour Impact on Unsteady Flow Past a Parabolic Accelerated Vertical Plate with Uniform Temperature and Mass Diffusion

S Kavitha[1], **A Selvaraj**[2]*

1 Research Scholar, Department of Mathematics, Vels Institute of Science, Technology & Advanced Studies, Chennai, 600117, Tamil Nadu, India
2 Department of Mathematics, Vels Institute of Science, Technology & Advanced Studies, Chennai, 600117, Tamil Nadu, India

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* **Corresponding author**.

aselvaraj_ind@yahoo.co.in

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Abstract

Objective: Fluid dynamics and heat transfer theory examine the Dufour phenomenon and the rotational influence of unstable parabolic flow across an accelerating infinite vertical plate. This scenario involves several parameters, including the ”mass Grashof number (Gr), thermal Grashof number (Gc), Prandtl number (Pr), Hartmann number (Ha), Schmidt number (Sc), Dufour number (Dc), and acceleration parameter”. **Method:** We have applied the Laplace transform method to the resulting PDE. This method converts the equations to algebraic form, making it easier to solve for velocity, temperature, and concentration in terms of time and space. Graphs can show the relationship between the acceleration parameter and numerous parameters such as mass and thermal Grashof, Hartmann (Ha), and Dufour (Df), as well as the consequent velocity profile. If the velocity increases when these variables change, we'll look at the physical reasons that generate this behaviour. We will examine the conclusions using experimental data or existing theoretical models, considering the model's assumptions and limits. Finally, highlight the significant facts and insights gained from the analysis. We will discuss potential future research possibilities, such as exploring more complex geometries or accounting for new physical effects. **Findings:** The increase in Dufour parameter value causes an increase in temperature and level trends, demonstrating the significant influence of these factors on the researched phenomena. **Novelty:** This research advances our understanding of heat and mass transfer phenomena by isolating the Dufour effect in a novel scenario involving unsteady flow around a rotating vertical plate, filling a gap in the existing body of knowledge that is dominated by MHD-inclusive investigations. **Suggestions**: This approach is fairly general and may be applied to find analysis of heat and mass transfer on Dufour effect for other effects such as Soret effect, Hall current of heat and mass transfer.

Keywords: Uniform Temperature; Thermo diffusion (Dufour); Inverse Laplace; Rotational; Constant Mass

1 Introduction

Different transport mechanisms that facilitate HMT (Heat & Mass Transfer), located in both nature and invention. Due to the buoyant forces caused by changes in concentration and warmth. When the mutual sharing of warmth and mass in an unstable liquid occurs immediately, and there is a considerable lot of unpredictability in the interactions between the driving potentials and the motions. The gradients in temperature and concentration produce energy fluxes. The Dufour effect generates energy circulation, although the Soret effect generates mass circulation. Those results perform an essential function once there are dissimilarities in the density of the stream movement. There can be large Dufour effects when a species moves from a liquid domain to a surface, particularly if the surrounding fluid has a lower density.

There are several industrial uses, including as the refining crude oil, processing molten polymers, handling pulps, papermaking, and aiding in the cooling of threads are some of its industrial applications, alongside facilitating textile manufacturing. We can advance fundamental understanding and contribute to the development of more accurate predictive models and practical engineering solutions by conducting systematic investigations into the combined impact of rotation and the Dufour effect on unsteady flow past a parabolic accelerated vertical plate.

The effects of thermal radiation on unsteady MHD flow of viscous incompressible electrically conducting fluid past an impulsively initiated oscillating vertical plate with changing temperature and constant mass diffusion in the presence of Hall current are discussed in [1]. The effect of Dufour number on flow patterns and heat transfer rates on an exponentially accelerated vertical plate with MHD flow and chemical reaction is examined in [2]. The influence of Hall current, radiation, Soret, and Dufour on an unstable MHD The article discusses natural convection flow over an infinite vertical plate set in a porous material in [3]. The study of heat and mass transfer (HMT) fluid flow across an exponentially accelerating vertical plate with an applied magnetic field and viscous dissipation is discussed in [4]. [5] Investigates the flow of nanofluids along an upward cone, as well as heat transfers caused by heat generation and thermal radiation. [6] Examines heat and mass transfer, the current study attempts to analyze the impacts of thermal radiation, Dufour effect, on the magnetohydrodynamic boundary layer flow through a vertical spinning cone in porous media.

The effects of parabolic flow on rotation on a plate that is vertical, taking convective HMT, chemical reactions, other factors into account is studied in [7]. The impact of chemical reaction and radiation on an unstable two-dimensional laminar flow around a viscous fluid over a semi-infinite, vertical absorbent surface that travel is examined in [8]. A numerical study of the Soret-Dufour effects on the motion of an unstable, viscous, and incompressible MHD flow through a semi-infinite, permeable inclined plate immersed in a variable-temperature, mass-diffusing porous medium is studied in [9]. In [10], the problem of a two-dimensional steady, MHD convective, incompressible, viscous flow past a uniformly moving semi-infinite vertical porous plate embedded in a porous medium is investigated, in the presence of radiation heat absorption, thermal radiation, thermal diffusion with constant heat and mass flux. [11] Investigates how hall current, Dufour effect, and Soret effect transient MHD flow across an inclined porous plate.

[12] Investigates numerically the spontaneously convective flow across an exponentially accelerating plate with viscous dissipation using the MHD finite element method. The effects of heat stratification on unsteady parabolic flow past an infinite vertical plate with chemical reactions are investigated in [13]. [14] Examined the free convection MHD flow of a viscous, chemically reactive, electrically conducting, incompressible, and

Casson fluid past a parabolically accelerated vertical plate, as well as heat and mass transfer in the incidence of thermal radiation.[15] Explores MHD regular heat transfer convective effect of mass transfer flow subject of initially incompressible viscous flow past an attracted exponentially accelerated vertical plate.[16] Discusses accelerated isothermal vertical plates and their heat and mass transfer features.

[17] Discusses the effects of thermal radiation on the unsteady MHD flow of viscous incompressible electrically conducting fluid past an impulsively initiated oscillating vertical plate with changing temperature and constant mass diffusion in the presence of Hall current. Investigate the heat and mass transmission process through a sheet that is assumed to stretch exponentially in a porous medium on MHD flow with suction, constant surface heat, and mass flux.[18] Explores how temperature-dependent fluid characteristics may increase the heat transfer efficiency and performance evolution of hybrid nanofluid in the presence of transverse magnetic field over a moving thin needle. In[19], Dufour effect belongings are studied for unequal magnetohydrodynamic assorted convective stream over a placed holey moving shield, with thermal emission, heat assimilation, and homogeneous substance reactions subjected to changeable suction.

[20] Investigates the effects of magnetic fields, radiant heat, and the hall effect on a stream passing a parabolic accelerating isothermal perpendicular plate. Computational analysis of MHD-driven bio-convective flow of hybrid Casson nanofluid across a permeable exponential stretching sheet, with thermophoresis and Brownian motion effects is studied in[21]. In[22] The purpose of work is to investigate the effect of inclination angle on mixed convection hybrid ferro-fluid flow on a porous shrink surface, taking into account heat sources and convective boundary conditions.

1.1 Comparative Study

In this section, we will look at the basic components, advantages, limitations, and practical issues associated to MHD free heat and mass transfer on Dufour effect, with a comparison analysis. Heat and mass transfer on Dufour effect with various action provide a useful framework for designing experiments using various parameters.

In[2] they have estimated the effect of the Dufour number on flow patterns and heat transfer rates in an exponentially accelerated vertical plate under these conditions could reveal important information about how these parameters act in situations in the real world. It could have consequences for a variety of engineering applications, including heat exchangers, chemical reactors, and material processing.

In[11] researchers have worked with nonlinear equations in this case due to the presence of multiple physical variables and how they interacted. Such equations are often solved using advanced mathematical approaches such as numerical methods or perturbation methods.

In[16] researchers may be fascinated by investigating how these parameters affect various flow features like as velocity, temperature, concentration profiles, skin friction, heat transfer rate, and species conversion rates. MHD, variable mass diffusion, thermal radiation, and chemical reactions can all have a major impact on these properties.

2 Methodology

This scenario considers a viscous and incompressible fluid that can conduct electricity flowing through a non-conductive vertical plate at y=0. The vertical axis is taken as x direction whereas the perpendicular to that is y direction. The formula for the velocity is $q=t^2$. It's crucial to remember that the pressure doesn't change across the flow field. The acquired results are predicated on the various components of the velocity vector being described by the continuity equation being satisfied. The flow characteristics under these circumstances are just dependent on z and t. Under these assumptions, the transient movement is controlled by the equations:

$$\frac{\partial u}{\partial t'} - 2v\Omega' = g(\beta T^0 - \beta T^0_\infty + \left(\beta^* C' - \beta^* C'_\infty\right)) + \frac{v\partial^2 u}{\partial z^2} \tag{1}$$

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

$$\frac{\partial T^0}{\partial t} = \frac{k}{\rho Cp}\frac{\partial^2 T^0}{\partial y^2} + \frac{DmK_T}{CsCp}\frac{\partial^2 C'}{\partial y^2} \tag{3}$$

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

Given the starting and stopping points

$u = v = 0, T^0 = T^0_\infty, C' - C'_\infty = 0$, for every $y, t' \le 0$

$t' > 0: \; u = u_0 t'^2, T^0 - T^0_\infty = At'\left(T^0_w - T^0_\infty\right), C' - C'_\infty = At'\left(C'_w - C'_\infty\right)$ at y=0

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

letting $A = \frac{u_0^{2/3}}{v^{\frac{1}{3}}}$

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

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

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

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

The following has been deduced using (Equation (6)) in Equations (1), (2), (3) and (4):

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

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

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

$$\frac{\partial C}{\partial t} = \frac{1}{sc}\frac{\partial^2 C}{\partial Z^2} \tag{10}$$

with the beginning and limits are

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

$$t' > 0 \quad u = u = u_0 t'^2, T^0 = T^0_w, C' = C'_w \;\; at\, y = 0 \tag{11}$$

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

The group of calculations Equations (7) and (8), involving the boundary constraint (Equation (11))

$$\frac{\partial q}{\partial t} = Gr\theta + GcC + \frac{\partial^2 q}{\partial Z^2} - mq \tag{12}$$

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

$$\frac{\partial C}{\partial t}=\frac{1}{sc}\frac{\partial^2 C}{\partial Z^2} \tag{14}$$

For non-dimensional quantities, these are the starting and stopping conditions.

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

$$t\ >\ 0 \quad q=t^2,\ \theta=1=C,\ as\ Z=0 \tag{15}$$

q tends to 0, θ tends to 0, C tends to 0 as Z approaches 0

Using Laplace transform, the solutions are then produced by performing an inverse transform at the end.

$$q=q_1-q_2+q_3-q_4-q_5 \tag{16}$$

$$q_1=\frac{(\eta^2+2i\Omega t)t}{42i\Omega}\left[\begin{array}{l}\left(e^{2\eta\sqrt{2i\Omega t}}erfc\left(\eta+\sqrt{2i\Omega t}\right)+e^{-2\eta\sqrt{2i\Omega t}}erfc\left(\eta-\sqrt{2i\Omega t}\right)\right)\\ +\frac{\eta\sqrt{t}(1-42i\Omega t)}{82i\Omega^{\frac{3}{2}}}\left(e^{-2\eta\sqrt{2i\Omega t}}erfc\left(\eta-\sqrt{2i\Omega t}\right)-e^{2\eta\sqrt{2i\Omega t}}erfc\left(\eta+\sqrt{2i\Omega t}\right)\right)-\frac{\eta t}{22i\Omega\sqrt{\pi}}e^{-(\eta^2+2i\Omega t)}\end{array}\right]$$

$$q_2=\frac{Gr}{a(1-pr)}\left[\begin{array}{l}\frac{1}{2}\left(e^{2\eta\sqrt{2i\Omega t}}erfc\left(\eta+\sqrt{2i\Omega t}\right)+e^{-2\eta\sqrt{2i\Omega t}}erfc\left(\eta-\sqrt{2i\Omega t}\right)\right)-erfc(\eta\sqrt{sc}\\ -\frac{e^{bt}}{2}\left(e^{2\eta\sqrt{(2i\Omega+b)t}}erfc\left(\eta+\sqrt{(2i\Omega+b)t}\right)+e^{-2\eta\sqrt{(2i\Omega+b)t}}erfc\left(\eta-\sqrt{(2i\Omega+b)t}\right)\right)\\ +\frac{e^{at}}{2}\left(e^{2\eta\sqrt{prat}}erfc\left(\eta\sqrt{pr}+\sqrt{at}\right)+e^{-2\eta\sqrt{prat}}erfc\left(\eta\sqrt{pr}-\sqrt{at}\right)\right)\end{array}\right]$$

$$q_3=\frac{Gc}{b(1-sc)}\left[\begin{array}{l}\frac{1}{2}\left(e^{2\eta\sqrt{2i\Omega t}}erfc\left(\eta+\sqrt{2i\Omega t}\right)+e^{-2\eta\sqrt{2i\Omega t}}erfc\left(\eta-\sqrt{2i\Omega t}\right)\right)-erfc(\eta\sqrt{sc}\\ -\frac{e^{bt}}{2}\left(e^{2\eta\sqrt{(2i\Omega+b)t}}erfc\left(\eta+\sqrt{(2i\Omega+b)t}\right)+e^{-2\eta\sqrt{(2i\Omega+b)t}}erfc\left(\eta-\sqrt{(2i\Omega+b)t}\right)\right)\\ +\frac{e^{bt}}{2}\left(e^{2\eta\sqrt{scbt}}erfc\left(\eta\sqrt{sc}+\sqrt{bt}\right)+e^{-2\eta\sqrt{scbt}}erfc\left(\eta\sqrt{sc}-\sqrt{bt}\right)\right)\end{array}\right]$$

$$q_4=\frac{DfPrScGr}{a\,(Pr-1)(Sc-Pr)}\left[\begin{array}{l}\frac{1}{2}\left(e^{-2\sqrt{2i\Omega t}\eta}erfc\left(\eta-\sqrt{2i\Omega t}\right)+e^{2\eta\sqrt{2i\Omega t}}erfc\left(\eta+\sqrt{2i\Omega t}\right)\right)-erfc(\eta\sqrt{pr})\\ -\frac{e^{at}}{2}\left(e^{2\eta\sqrt{(2i\Omega+a)t}}erfc\left(\eta+\sqrt{(2i\Omega+a)t}\right)+e^{-2\eta\sqrt{(2i\Omega+a)t}}erfc\left(\eta-\sqrt{(2i\Omega+a)t}\right)\right)\\ +\frac{e^{at}}{2}\left(e^{2\eta\sqrt{prat}}erfc\left(\eta\sqrt{pr}+\sqrt{at}\right)+e^{-2\eta\sqrt{prat}}erfc\left(\eta\sqrt{pr}-\sqrt{at}\right)\right)\end{array}\right]$$

$$q_5=\frac{DfPrScGr}{(Sc-Pr)(Pr-1)b}\left[\begin{array}{l}erfc(\eta\sqrt{sc}-\frac{1}{2}\left(e^{2\eta\sqrt{2i\Omega t}}erfc\left(\eta+\sqrt{2i\Omega t}\right)+e^{-2\eta\sqrt{mt}}erfc\left(\eta-\sqrt{2i\Omega t}\right)\right)\\ -\frac{e^{bt}}{2}\left(e^{2\eta\sqrt{scbt}}erfc\left(\eta+\sqrt{(Scb)t}\right)+e^{-2\eta\sqrt{scbt}}erfc\left(\eta-\sqrt{(Scb)t}\right)\right)\\ +\frac{e^{bt}}{2}\left(e^{2\eta\sqrt{(2i\Omega+b)t}}erfc\left(\eta+\sqrt{(2i\Omega+b)t}\right)+e^{-2\eta\sqrt{(m+b)t}}erfc\left(\eta-\sqrt{(2i\Omega+b)t}\right)\right)\end{array}\right]$$

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

$$\theta=erfc\left(\eta\sqrt{Pr}\right)+\frac{DfPrSc}{Sc-Pr}\left[erfc\left(\eta\sqrt{Pr}\right)-erfc\left(\sqrt{\eta^2\,Sc}\right)\right] \tag{18}$$

$$erfc(c+i\,b)=erf(c)+\frac{exp(-c^2)}{2c\pi}\left[1-cos\,2\,(cb)+isin\,2(cb)\right]+\frac{2\,e^{-c^2}}{\pi}\sum_{n=1}^{\infty}\frac{e^{\frac{-\eta^2}{4}}}{\eta^2+4c^2}\left[f_n\,(c,b)+ig_n\,(c,b)\right]+\epsilon\,(c,b)$$

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

f_n = 2c – 2c cos 2(cb) cos h(bn) + n) sin 2(cb) sinh (bn)

g_n =2 c sin 2(cb) cosh(bn) + n cos 2(cb) sinh (bn)

$$|\epsilon(c,b)|\approx\approx\frac{1}{10^{16}}\,|erf(c+ib)|$$

3 Results and Discussion

Numerical simulations are used to acquire insights and improve knowledge of the problem by varying the physical parameters (e.g., Du, Pr, Sc, Gr, and Gc) according to the features of the flow and transport processes. 0.71, which is similar to the Prandtl number of air, is selected. The aforementioned factors' numerical values for concentration, temperature, and velocity are then added together.

Figure 1 shows the Concentration graph, which shows consistency between the various Schmidt (Sc) values. It is evident that the expected Schmidt values fall with raising wall concentration.

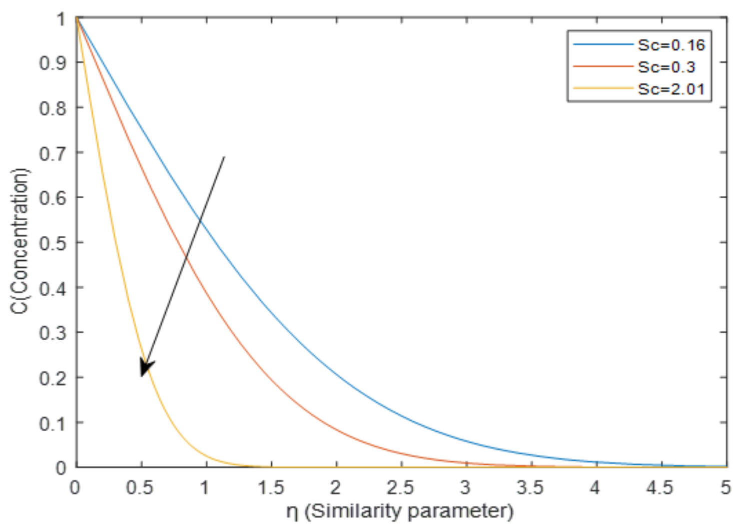

Fig 1. Concentration chart for different Schmidt Number (Sc) Values

The temperature of fluid fluxes in both air and water is affected by Dufour's mixed impact on temperature, with the air flow having a greater temperature than the water flow. Figure 2 highlights that boosts, Prandtl (Pr) correspond to a falling in warmth.

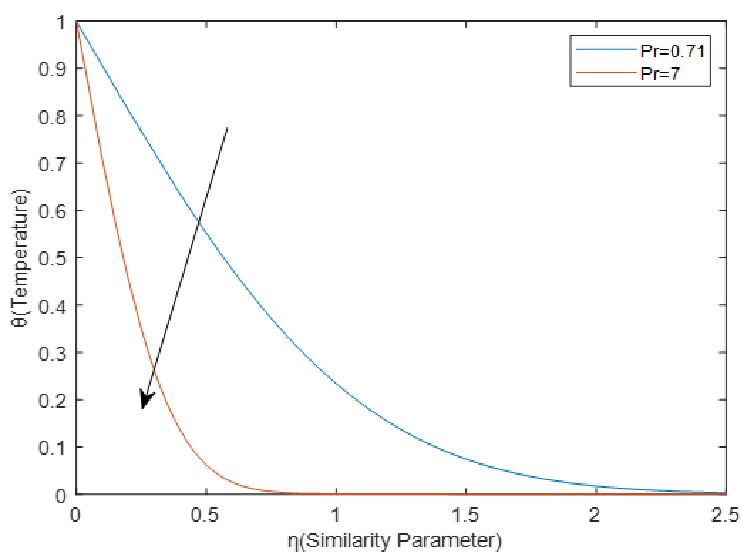

Fig 2. Temperature tendency for distinct Prandtl number (Pr)

Figure 3 shows the temperature evolution during instances of t = 0.1, 0.2, and 0.3. We may analyze the data by taking heat-related characteristics into account as well as the Dufour, Prandtl, and Schmidt numbers. As time went on, it became clear how sensitive the fluid was to a rise in temperature. The increased estimate of time boosts the temperature.

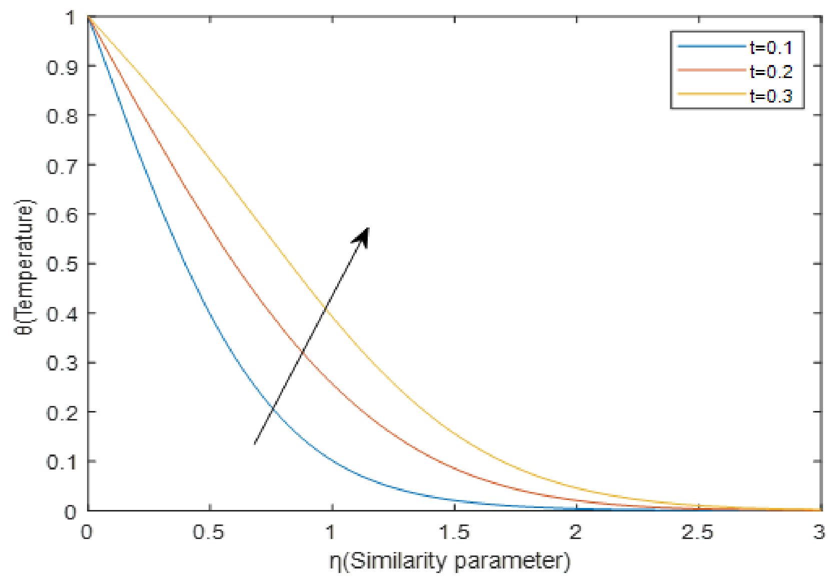

Fig 3. Temperature graph distinct t

In Figures 4 and 5, we can study the temperature's trajectory for Dufour (Df) numbers. Overall, the Dufour (Df) number indicates a raise in temperature.

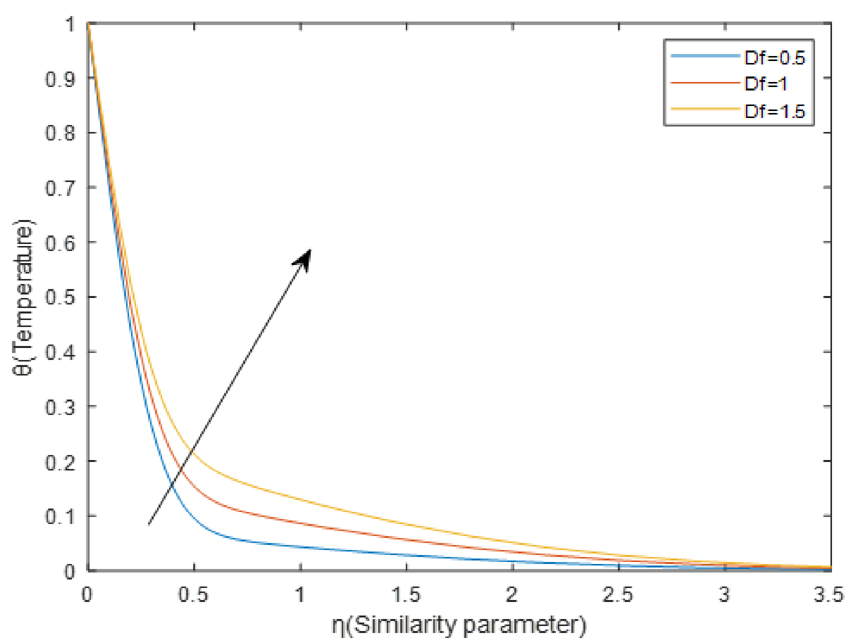

Fig 4. Temperature for Df values (Pr=7)

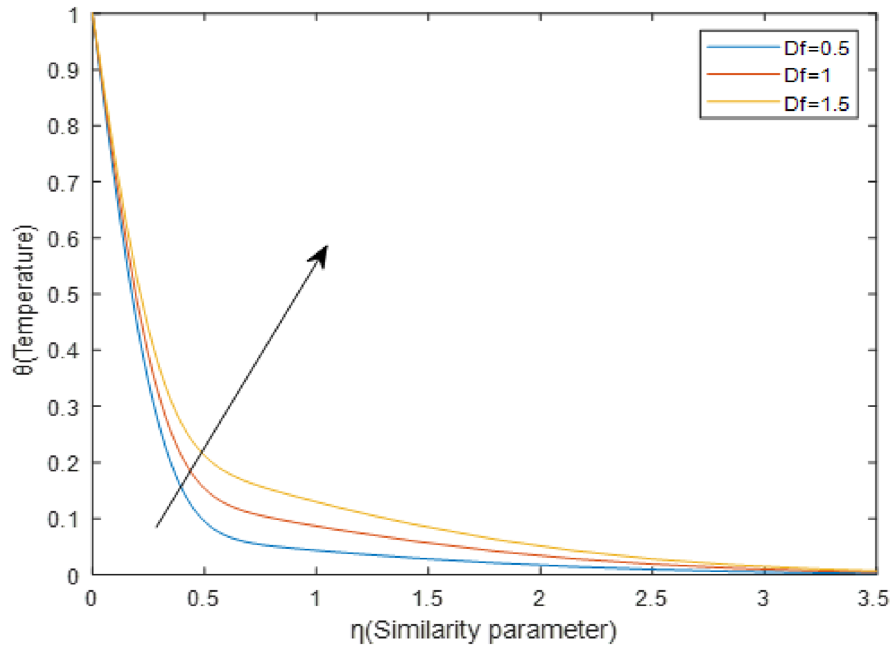

Fig 5. Temperature Trend for various values of Df (Pr=0.71)

Figure 6 shows the temperature's temporal history over Schmidt numbers Sc = 0.16, 0.6, and 2.01, resulting in a drop in overall temperature at this phase.

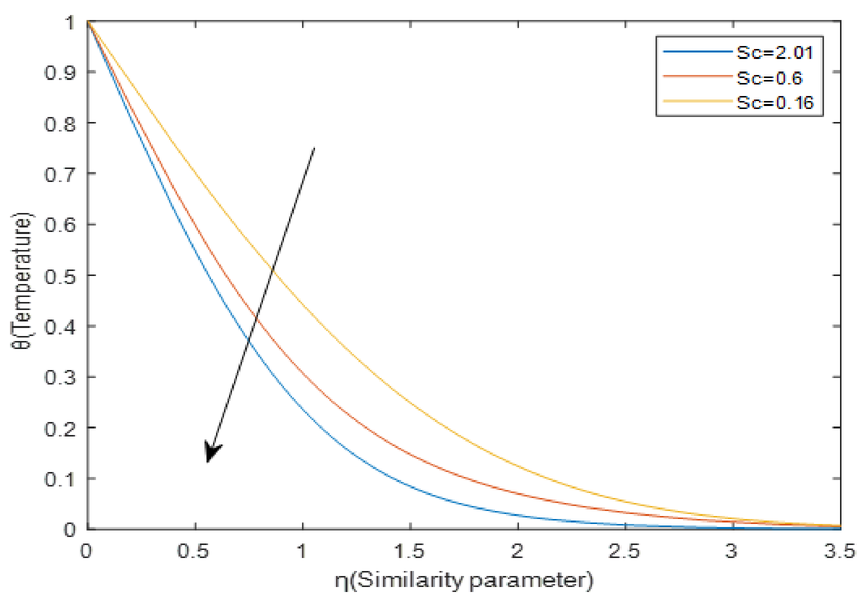

Fig 6. Temperature Graph for distinct Sc

Figure 7 indicates plate's speed according to different Dufour Df numbers (Df = 0.5, 1, 1.5), with the maximum velocity entered as the Dufour number grows. It indicates a beneficial connection between the Dufour number and the plate's velocity.

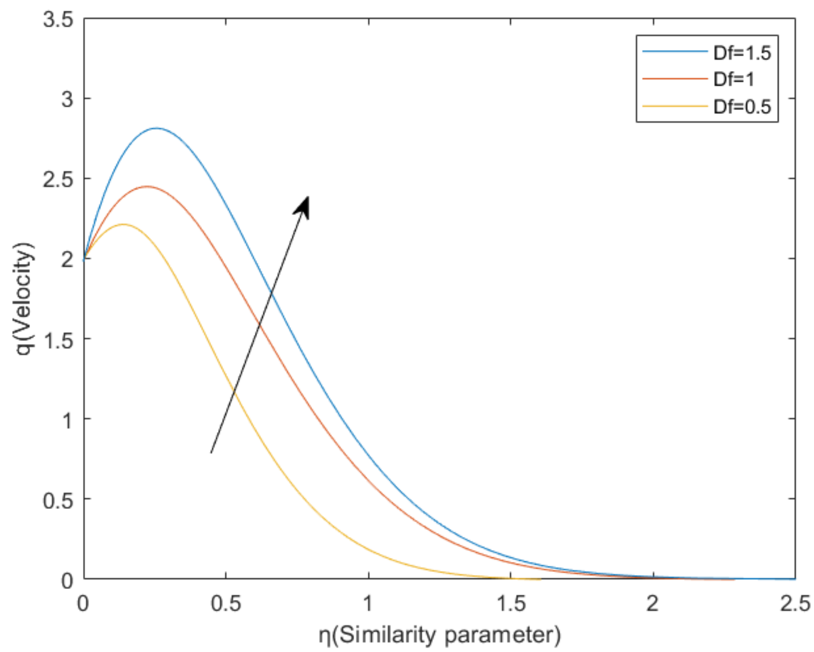

Fig 7. Velocity (Speed) profile for various values of Df

Figure 8 appears to provide speed gradients across the plate with multiple Schmidt (Sc) numbers (Sc = 0.16, 0.3, and 0.6), with the Schmidt number dropping as plate speed raises.

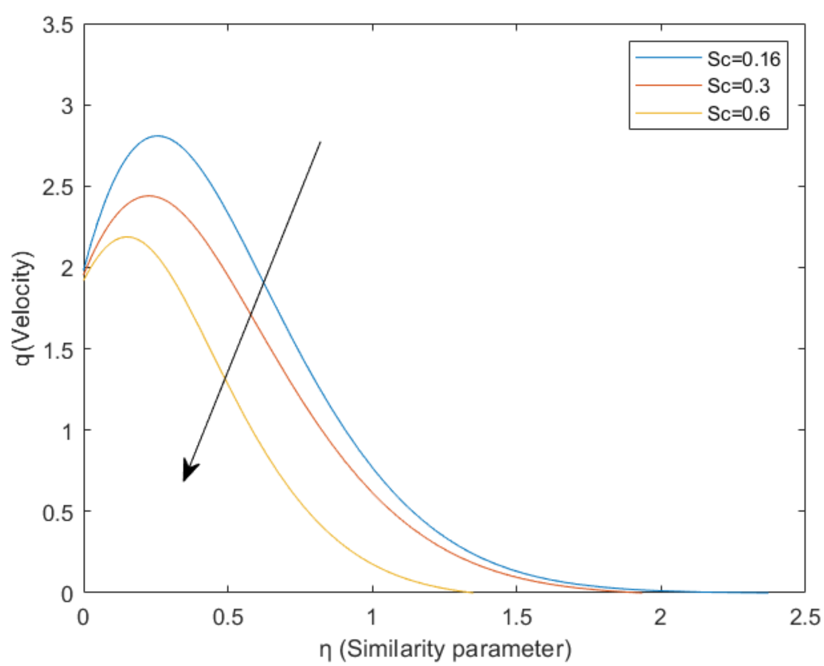

Fig 8. (Speed) Velocity contour with distinct Sc

Velocity profiles are shown in Figure 9 at various Grashof numbers (Gr = 2, 5, 7), where higher Gr values are associated with faster velocities.

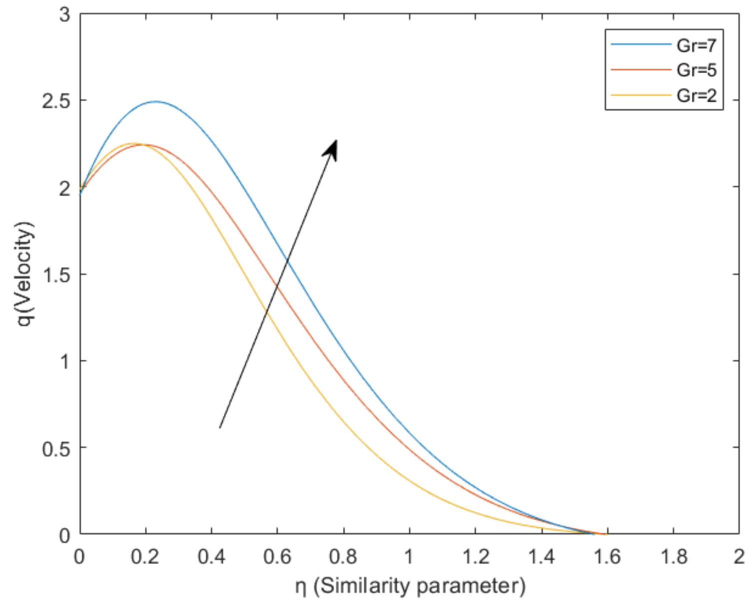

Fig 9. (Speed) Velocity sketch for unlike values of Thermal (Gr)

Figure 10 displays, Gc appears to be a parameter that controls fluid flow around the plate, with greater Gc values resulting in higher fluid velocities near the plate.

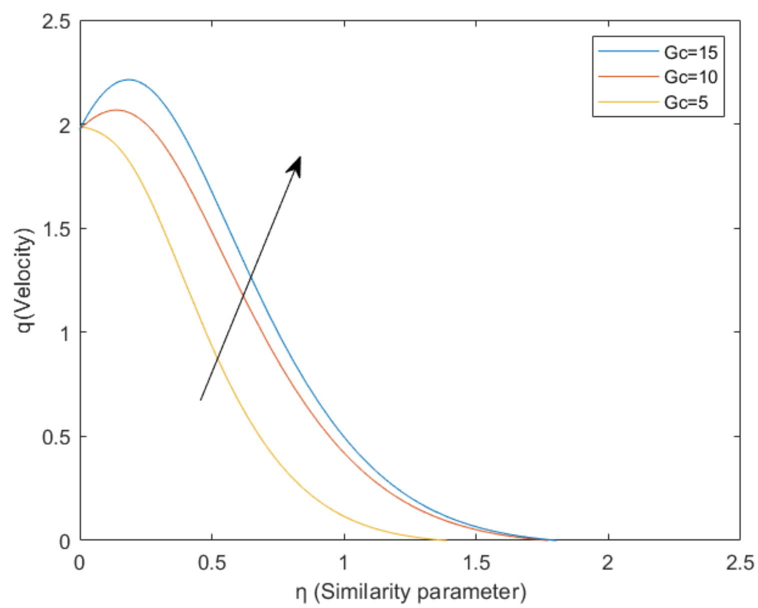

Fig 10. Velocity sketch for altered values of Gc

Rotation produces additional forces that deflect and sustain the flow, regulating the thickness and behaviour of the layer of boundaries.

The Dufour effect supplies additional heat fluxes as a result of mass diffusion, modifying temperature profiles and connecting energy and mass transfer processes.

In an unsteady flow instance with parabolic acceleration, these effects promote complex interactions and time-dependent responses in the velocity, temperature, and concentration domains, resulting in an exciting and complicated flow dynamics model.

4 Conclusion

This study explores the relationship between Dufour effects and rotational effects in a shaky stream across a vertical plate which is isothermal plate under parabolic acceleration with temperature. The fundamental mathematical statements of the flow are interpreted by the application of Inverse Laplace transforms, which aids in the understanding of the equations. Despite these constraints, studying the influence of rotation and the Dufour effect on unsteady flow reveals important information about the complicated interactions between fluid motion, heat transfer, and mass diffusion. Graphs, a helpful tool for presenting data and highlighting distinctions, are used to clarify all of the study's conclusions. We may systematically examine the individual and combined impacts of rotation and the Dufour effect on unsteady flow past a parabolic accelerated vertical plate, resulting in a full comprehension of the underlying physical phenomena and their consequences. Despite these constraints, studying the influence of rotation and the Dufour effect on unsteady flow reveals important information about the complicated interactions between fluid motion, heat transfer, and mass diffusion. The future prospects for studying the effects of rotation and the Dufour effect on fundamental understanding, enabling technological innovation, and addressing practical engineering difficulties.

Based on the results,

- With regard to the Schmidt number, the graph indicates that longer times result in thicker walls and vice versa.
- The temperature profiles increase when Df, Gr, and t are raised. In contrast, as the experiment progresses, the Prandtl and Schmidt numbers show continuous variations in temperature in the water and air media.
- Regarding the Prandtl, Schmidt, and Dufour numbers, the velocity shows a continuous decrease. On the other hand, the profiles show a significant rise in velocity with respect to the Grashof figures for mass, warmth, and time.

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