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THE INFLUENCE OF THERMAL EXPANSION ON FLOW PAST AN INCLINED ACCELERATED SECTIONAL PLATE WITH PERSISTENT MASS DIFFUSION

G. NAGARAJAN* and M. SUNDAR RAJ
Department of Mathematics, Panimalar Engineering College
Poonamallee, Chennai 600123, Tamil Nadu, INDIA
E-mail: sridinnaga@gmail.com

R MUTHUCUMARASWAMY
Department of Applied Mathematics, Sri Venkateswara College of Engineering
Sriperumbudur 602117, Tamil Nadu, INDIA

In this article, we examined the solution of a homogeneously intensified isothermal inclined infinite plate with constant temperature. The plate is elevated to T_w, and the species accumulation is enhanced at a consistent speed. Under appropriate boundary conditions, the non-dimensional guiding formulae are remedied using the Laplace transform procedure. The effect of velocity, temperature, and concentration on various factors, including thermal and mass Grashof numbers, Schmidt numbers, and duration, is discussed. The velocity increases proportionally to the thermal and mass Grashof numbers, but decreases as the inclined angle, Schmidt numbers and time increase.

Key words: thermal expansion, mass diffusion, accelerated, inclined plate, isothermal.

1. Introduction

Separation procedures, the evaporation of permeable components in garment manufacturing and the moistening of permeable substances by contaminants, biomechanics, petroleum engineering, conservation of atomic plants, demarcation interface regulation in aircraft and spacecraft design, solar energy collectors, moisture of agricultural fields, geothermal energy extraction, oil and gas industries, fog formation and dispersion are all examples of where mixed heat and mass transfer are important.

Gebhart and Pera [1] investigated the characteristics of perpendicular spontaneous convective movements caused by a combination of heat and mass dispersion buoyant factors. Fujii and Imura [2] explored natural convection heat transfer from a plate with variable tilt. Using the perturbation approach, Gupta *et al.* [3] investigated the effects of unrestricted circulation past a propelled perpendicular slab in an immiscible diffusive liquid. An approximate limited study of transitory unrestricted convective flow over a quasi perpendicular flattened surface with mass transference was made by Soundalgekar and Ganesan [4]. The consequences of mass transmission on flow across a continuously propelled perpendicular surface were also investigated by Soundalgekar [5]. The consequences of MHD flow on unrestricted convective circulation of an electrically conductive liquid through an advanced perpendicular surface were studied by Raptis and Singh [6]. Das *et al.* [7] examined the influence of mass transference on circulation through a spontaneously initiated indefinite perpendicular panel with synthetic activity as well as sustained thermal flow. Muthucumaraswamy and Ganesan [8] looked into the first level reaction on a circulation through a perpendicular surface that was spontaneously initiated and had a consistent thermal as well as mass influx. Singh and Singh [9] investigated thermal as well as mass transmission in MHD flow on circulation of a viscid liquid through a perepndicular surface having undulating assimilation movement. Molla *et al.* [10] studied the influence of intrinsic thermal

* To whom correspondence should be addressed

origination on a continuous 2-D spontaneous convective movement across a perpendicular undulating substrate incorporating thermal origination. The viscid movement across an arbitrary extending surface amidst a synthetic process as well as a magnetized environment was studied by Raptis and Perdikis [11].

Muthucumaraswamy *et al.* [12] investigated the impact of thermal flow and irregular mass propagation on transference across a raised perpendicular surface. Deka [13] investigated the Hall current influences on magnetohydrodynamic surge across an expedited lateral surface in the vicinity of a whirling medium. Synthetic interactions as well as irradiation impacts on magnetohydrodynamic flow circulation across a limitless perpendicular surface having variable levels were explored by Rajesh and Varma [14]. Muthucumaraswamy *et al.* [15] analysed an undulating perpendicular panel in the midst of a first-level synthetic process. PK Singh [16] explored the 2D hydro-magnetic convective flow of a viscous, electrically conducting fluid through an inclined plate in a porous material. The various implications of magnetohydrodynamic flow through a permeable material over an advanced surface in a rotary environment were investigated by Chauhan and Rastog [17]. In the context of synthetic reactivity as well as viscid diffusion, Barik *et al.* [18] studied the heat radiant impact on an intermittent magnetohydrodynamic surge over a slanted permeable warmed plate.

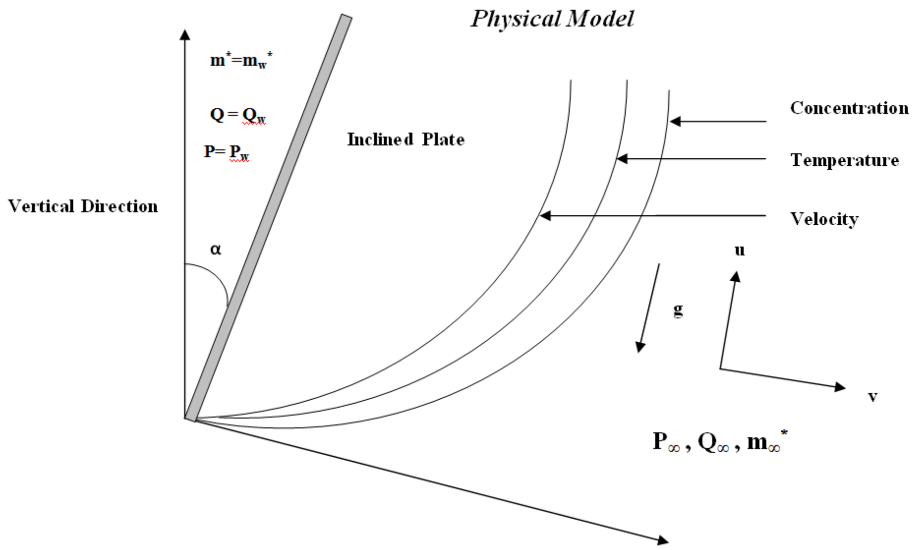
The influence of magnetohydrodynamics on a travelling perpendicular panel across permeable media in the midst of synthetic interaction was investigated by Tripathy *et al.* [19]. Sidda Reddy and Raju [20] investigated the radiative and Hall current implications on magnetohydrodynamic flow through an expedited slanted permeable sheet. Ramana Reddy *et al.* [21] investigated the effects of Hall current on the unstable circulation of a nano-fluid in an angled magnetic environment. Setha *et al.* [22] investigated the MHD unconstrained convection circulation across permeable media past a spontaneously advancing perpendicular slab in the vicinity of a slanted magnetostrictive source. Rajput and Gaurav Kumar [23] investigated the effects of Hall current on the magnetohydrodynamic surge across permeable media via an undulating slanted panel with varying temperatures, as well as material dispersion in the midst of synthetic interaction. The influences of thermal as well as mass transference on the MHD unconstrained convective circulation through an incessantly propelled slanted slab embedded in a permeable environment were explored by Dhal *et al.* [24]. Shankar *et al.* [25] investigated the effects of Hall current and irradiation on the MHD free convection movement in a permeable material via a sloped parabolic propelled panel with changing temperature.

The implications of Soret and Dufour numbers on radiant magnetohydrodynamic flow circulation of a chemical interacting liquid across an exponential propelled inclination surface via permeable environment in the vicinity of thermal retention as well as viscid dispersion were addressed by Venkateswarlu *et al.* [26]. Usharani *et al.* [27] investigated the influence of a magnetohydrodynamic flow through a 1st synthetic process involving varying material dispersion and heat transmission on an infinitely sloped perpendicular surface. In the context of a synthetic activity, Nazish *et al.* [28] studied the thermal as well as material transmission of spontaneous convection with a moveable slanted surface underneath a tilted magnetism environment. Azhar Ali Zafar *et al.* [29] investigated magnetohydrodynamic unrestricted convective surge of a specific category liquid across an inclined surface with thermal as well as material flow in the vicinity of an angled magnetism environment. Shamshuddin *et al.* [30] examined the heat as well as solutal behavior of copper oxide NPs on an arbitrary spirally spreading platform with a thermal emitter as well as molecular interaction. Magnetohydrodynamic as well as synthetic interaction of multi-walled carbon nanotubes of iron oxide hybridized NPs on an exponential permeable diminishing surface with slippage bounding were examined by Swain *et al.* [31]. Unrestricted magnetohydrodynamic surge with the consequence of speed slippage circumstance through a permeable tilted surface was computed by Preeti and Upendra [32]. The contamination influence on magnetohydrodynamic shear thinning liquid surge across a slanted arbitrary terrain involving synthetic interaction in a Forchheimer permeable content was studied by Shankar Goud Bejawada *et al.* [33].

2. Analysis

Examine how a viscid congealed liquid flows unevenly through a uniformly propelled arbitrary surface angled at α from the perpendicular plane. The X axis is considered along the vertical direction and the Y axis perpendicular to it. At time $t_1^* \leq 0$, both the plate and the liquid seem to be at the same temperature T_∞ .

At time $t_1^* > 0$, the plate is accelerated with a velocity $u = u_0 t_1^*$ in its individual level and the temperature from the plate is raised to T_w and the mass is dispersed from the surface to the liquid directly with time. Below is a schematic of the actual framework as well as the metric framework.



In Boussinesq's approximation, the unsteady flow is governed by the followin relations:

$$\frac{\partial u}{\partial t_1^*} = g\beta\cos\alpha\left(Q - Q_\infty\right) + g\beta_2{}^*\cos\alpha\left(m_1^* - m_\infty^*\right) + \nu\frac{\partial^2 u}{\partial y^2},$$

$$\rho C_p \frac{\partial Q}{\partial t_1^*} = k\frac{\partial^2 Q}{\partial y^2}, \tag{2.1}$$

$$\frac{\partial m_1^*}{\partial t_1^*} = D\frac{\partial^2 m_1^*}{\partial y^2},$$

with the following initial and boundary conditions:

$$t_1^* \le 0; \quad u = 0, \quad Q = Q_\infty, \quad m_1^* = m_\infty^* \quad \text{for all} \quad y \le 0,$$

$$t_1^* > 0: \quad u = u_0 t_1^*, \quad Q = Q_w, \quad m_1^* = m_w^* \quad \text{at} \quad y = 0, \tag{2.2}$$

$$u \to 0, \quad Q \to Q_\infty, \quad m_1^* \to m_\infty^* \quad \text{as} \quad y \to \infty$$

where

$$A = \left(\frac{u_0^2}{\nu}\right)^{\frac{1}{3}}.$$

Introducing the subsequent dimensionless parameters:

$$P=\frac{u}{(\nu u_0)^{\frac{1}{3}}},\qquad t_1=t_1^*\left(\frac{u_0^2}{\nu}\right)^{\frac{1}{3}},\qquad Y=y\left(\frac{u_0}{\nu^2}\right)^{\frac{1}{3}},$$

$$\varphi^*=\frac{Q-Q_\infty}{Q_w-Q_\infty},\quad Gr=\frac{g\beta(Q_w-Q_\infty)}{u_0},\quad m^*=\frac{m_1^*-m_\infty^*}{m_w^*-m_\infty^*},\tag{2.3}$$

$$Gc=\frac{g\beta_2^*(m_w^*-m_\infty^*)}{u_0},\qquad Pr=\frac{\mu C_p}{k},\qquad Sc=\frac{\nu}{D}$$

leads to mathematical formulas (2.1) to (2.4)

$$\frac{\partial P}{\partial t_1}=Gr\cos\alpha\,\varphi^*+Gc\cos\alpha\,m^*+\frac{\partial^2 P}{\partial Y^2},$$

$$\frac{\partial\varphi^*}{\partial t_1}=\frac{1}{Pr}\frac{\partial^2\varphi^*}{\partial Y^2},\tag{2.4}$$

$$\frac{\partial m^*}{\partial t_1}=\frac{1}{Sc}\frac{\partial^2 m^*}{\partial Y^2}.$$

In non-dimensional quantities, the corresponding boundary requirements are

$$\begin{array}{llllll} & P=0, & \varphi^*=0, & m^*=0 & \text{for all} & Y,t_1\le 0,\\ t_1>0: & P=t_1, & \varphi^*=1, & m^*=1 & \text{at} & Y=0,\\ & P\to 0, & \varphi^*\to 0, & m^*\to 0 & \text{as} & Y\to\infty. \end{array}\tag{2.5}$$

3. Resolution framework

The non-dimensional regulating formulae (3.1) to (3.3) are computed employing the standard Laplace-transform approach, utilising the baseline as well as threshold constraints (2.5). The findings are summarized below:

$$\varphi^*=\mathrm{erfc}\left(\frac{y}{2\sqrt{t_1}}\sqrt{Pr}\right),\tag{3.1}$$

$$m^*=\mathrm{erfc}\left(\frac{y}{2\sqrt{t_1}}\sqrt{Sc}\right),\tag{3.2}$$

$$P=(1-a-b)t_1\left[\left(1+\frac{y^2}{2t_1}\right)erfc\left(\frac{y}{2\sqrt{t_1}}\right)-\frac{y}{\sqrt{t_1\pi}}\exp\left(-\frac{y^2}{4t_1}\right)\right]+$$
$$+at_1\left[\left(1+\frac{y^2}{2t_1}\Pr\right)erfc\left(\frac{y}{2\sqrt{t_1}}\sqrt{\Pr}\right)-\frac{y\sqrt{\Pr}}{2\sqrt{\pi t_1}}\exp\left(-\frac{y^2}{4t_1}\Pr\right)\right]+ \tag{3.3}$$
$$+at_1\left[\left(1+\frac{y^2}{2t_1}Sc\right)erfc\left(\frac{y}{2\sqrt{t_1}}\sqrt{Sc}\right)-\frac{y\sqrt{Sc}}{\sqrt{\pi t_1}}\exp\left(-\frac{y^2}{4t_1}Sc\right)\right]$$

where

$$a=\frac{Gr\cos\alpha}{1-\Pr},\qquad b=\frac{Gc\cos\alpha}{1-Sc},\qquad \eta=\frac{y}{2\sqrt{t_1}}.$$

Skin Friction

$$\tau=-\left(\frac{\partial P}{\partial\eta}\right)_{\eta=0}=\frac{2\sqrt{t_1}}{\sqrt{\pi}}\left[1-a-b+a\sqrt{pr}+b\sqrt{sc}\right]. \tag{3.4}$$

Sherwood number

$$Sh=-\left(\frac{\partial m^*}{\partial y}\right)_{y=0}=\sqrt{\frac{Sc}{\pi t_1}}. \tag{3.5}$$

Nusselt number

$$Nu=-\left(\frac{\partial\varphi^*}{\partial y}\right)_{y=0}=\sqrt{\frac{\Pr}{\pi t_1}}. \tag{3.6}$$

4. Results and discussion

With continuous temperature as well as continual mass dispersion, the circulation past a sequentially expedited angled sheet has been investigated. In this section, we examine the velocity profile, temperature profile, as well as concentration profile for a wide range of variables such as the angle of inclination, thermal, and mass Grashof numbers, Prandtl numbers, Schmidt numbers, and time in figures from 1 to 13.

Figure 1 shows the velocity contour for various angles of tilt (α). It is revealed that the velocity increased while the angle (α) decreased. Also the velocity profiles for various values of the mass Grashof number Gc are presented in Fig.2. the figure shows that the velocity raises when Gc decrease. Figure 3 illustrates the effect of the velocity for various thermal Grashof numbers. It is seen that the velocity augments with reducing the thermal Grashof Gc number.

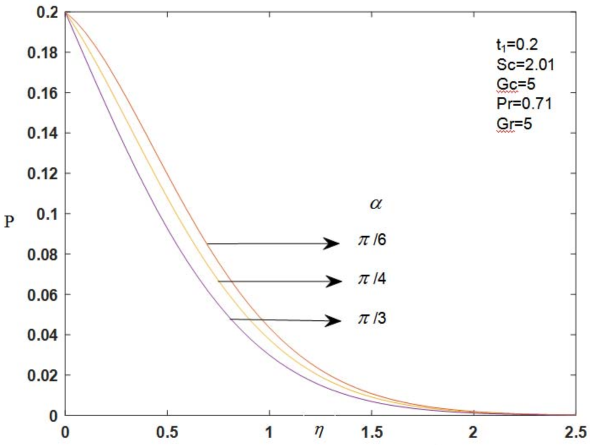


Fig.1. Velocity profile for different values of α .

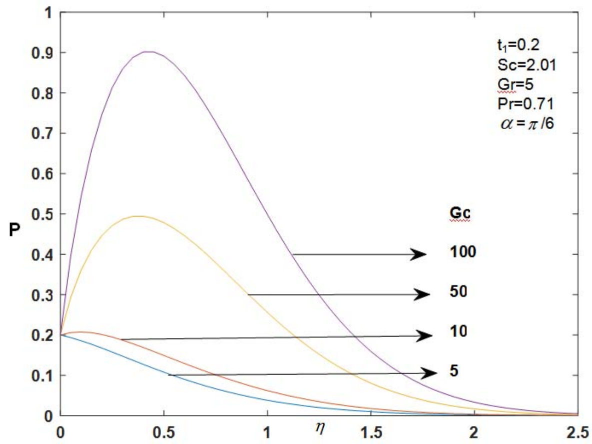


Fig.2. Velocity profile for different values of *Gc* .

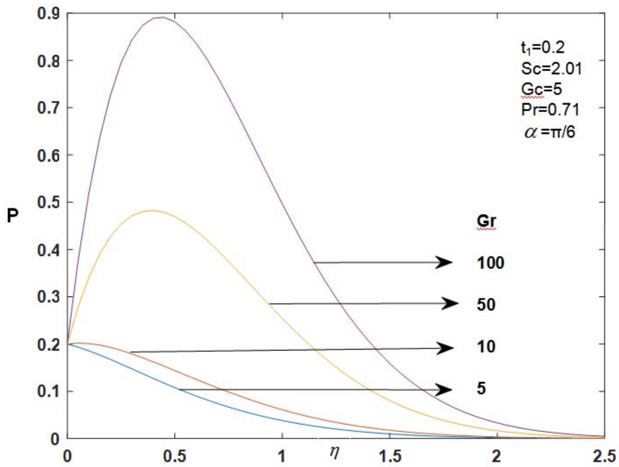


Fig.3. Velocity profile for different values of *Gr* .

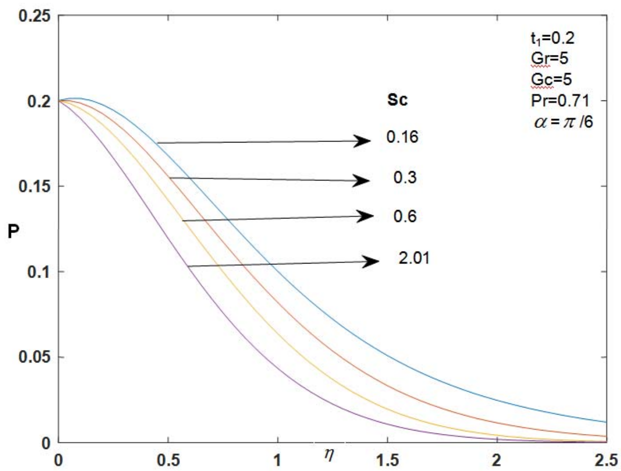


Fig.4. Velocity profile for different values of *Sc* .

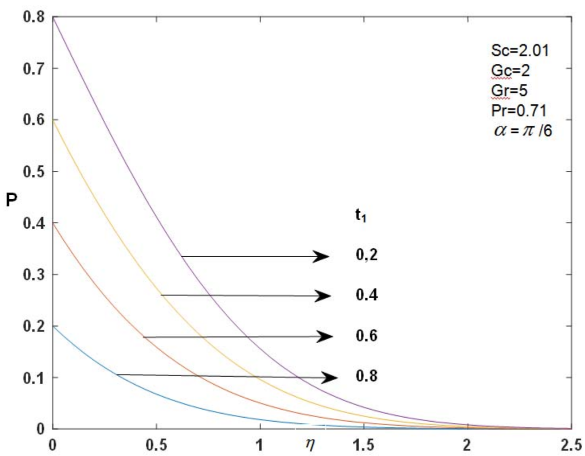


Fig.5. Velocity profile for different values of t_1 .

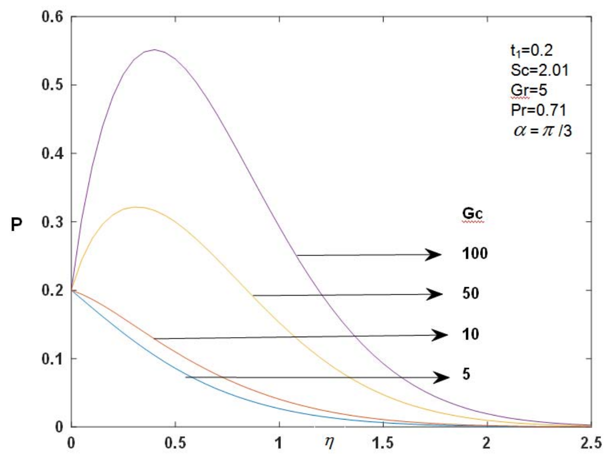


Fig.6. Velocity profile for different values of *Gc* .

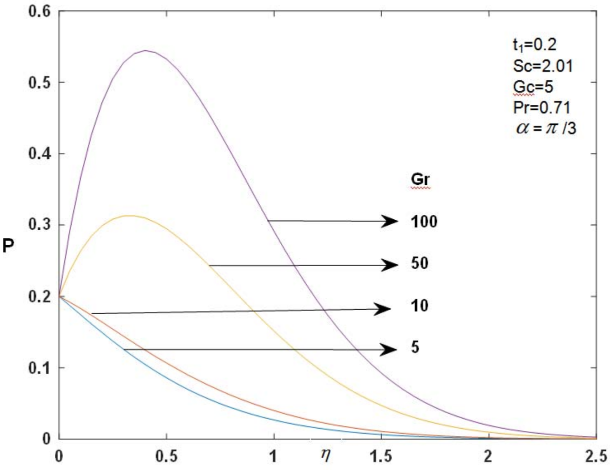


Fig.7. Velocity profile for different values of Gr .

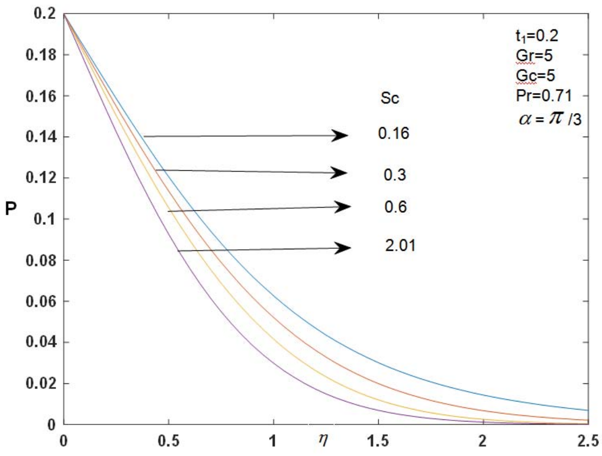


Fig.8. Velocity profile for different values of Sc .

Figure 4 presents the influence of the velocity for various values of the Schmidt number Sc when the angle of inclination is 30^o . Due to decreasing of Sc the velocity increases. The velocity profile for various values of time is shown in Fig.5. It is revealed that the velocity increases while the time is decreased. In Fig.6, the profile of velocity is shown for various numbers of Gc when the plate is inclined at 60^o . The velocity lifts up when the mass Grashof number grows. The effect of velocity is shown in Fig.7 for various values of the thermal Grashof number. It is observed that by augmenting Gr, the velocity also increases. Figure 8 reveals the velocity contours for various values of Sc when the angle of tilt is 60^o . As Sc decreases, so does the velocity.

The velocity shapes for various values of time is presented in Fig.9. It is seen that the velocity grows while the time reduces. Figure 10 shows the shapes of velocity contour for different values of Sc when the plate is inclined at 45^o . It is seen that decreasing Sc causes an increase in velocity. Figure 11 presents the temperature profile for various values of the Prandtl number $\Pr$. It shows that the heat increases when the Prandtl number decreases. Figure 12 also depicts the concentration profile for various values of the Schmidt numbers (Sc) . When Sc increases, the concentration decreases.

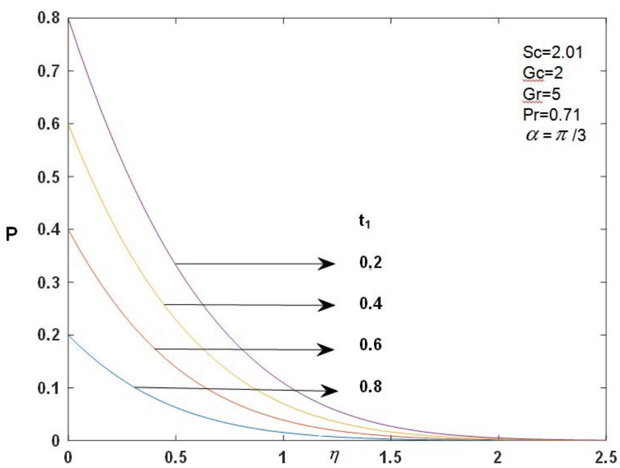


Fig.9. Velocity profile for different values of t_1 .

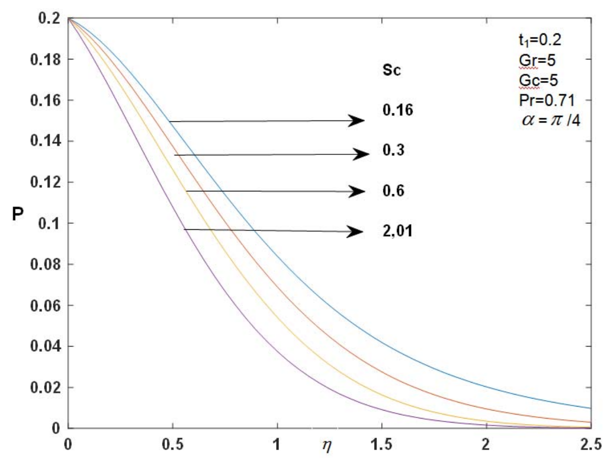


Fig.10. Velocity profile for different values of Sc .

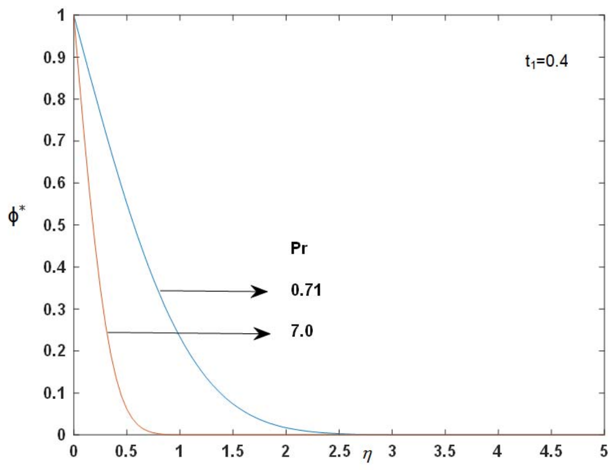


Fig.11. Temperature profile for different values of Pr .

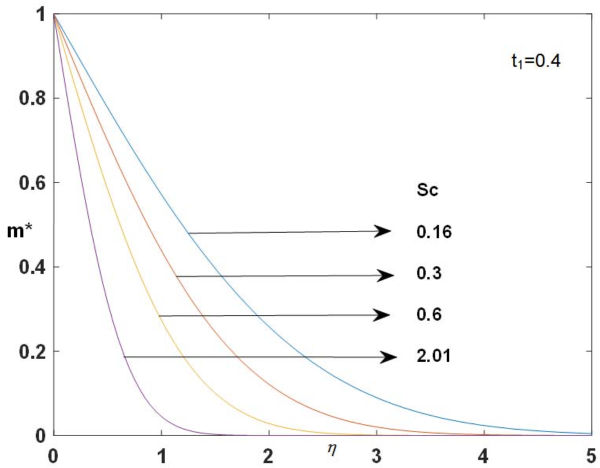


Fig.12. Concentration profile for different values of Sc .

Table 1 illustrates the consequences of the local skin friction (τ) for various factors such as the Prandtl, Schmidt numbers, thermal, mass Grashof numbers, and angles of inclination. The skin friction (τ) increases with an increasing angle of inclination, Prandtl and Schmidt numbers . But it has a reverse effect for increasing time, thermal and mass Grashof numbers.

Table 1. Skin friction values for various parameters.

α (degrees)	t_1	Pr	Sc	Gr	Gc	τ
30	*0.2*	*0.71*	*0.6*	*2*	*2*	*-0.4623*
30	*0.2*	*0.71*	*0.6*	*5*	*5*	*-1.9126*
30	*0.4*	*0.71*	*0.16*	*2*	*2*	*-0.5941*
45	*0.2*	*0.71*	*0.3*	*5*	*2*	*-0.9251*
45	*0.4*	*7.0*	*2.01*	*2*	*2*	*0.0191*
45	*0.6*	*0.71*	*0.6*	*2*	*2*	*-0.4938*
60	*0.2*	*0.71*	*0.6*	*2*	*2*	*-0.0541*
60	*0.4*	*0.71*	*0.6*	*5*	*5*	*-1.2614*
60	*0.4*	*7.0*	*0.6*	*5*	*5*	*-0.7822*
30	*0.2*	*7.0*	*0.3*	*2*	*5*	*-1.147*
30	*0.2*	*0.71*	*0.6*	*5*	*2*	*-1.1738*
45	*0.4*	*7.0*	*0.3*	*2*	*2*	*-0.2156*
45	*0.6*	*7.0*	*2.01*	*5*	*2*	*-0.4853*
60	*0.4*	*7.0*	*2.01*	*5*	*5*	*-0.5146*
60	*0.6*	*7.0*	*2.01*	*2*	*5*	*-0.27041*
45	*0.6*	*7.0*	*2.01*	*2*	*5*	*-0.74363*
45	*0.4*	*0.71*	*0.6*	*5*	*5*	*-2.0781*
60	*0.2*	*0.71*	*0.3*	*5*	*2*	*-0.50685*

Table 2 reveals the influence of physical factors Sc and t on the Sherwood number. It is clearly seen that by increasing the Schmidt number, the Sherwood number increases. Thus the mass transfer increases when Sc increases.

Table 2. Sherwood number.

t_1	Sc	Sh
0.6	0.3	0.5150
0.2	0.6	2.1850
0.2	2.01	3.9992
0.2	0.16	1.1283
0.4	0.16	0.5642
0.2	3	4.0886
0.3	4	3.7612
0.2	0.3	1.5451

Table 3 presents the Nusselt numbers Nu for various values of Pr and time. It shows that if we increase the Prandtl number, then Nu raises. Therfore, we conclude that the heat transfer increases while Pr increases.

Table 3. Nusselt number.

t_1	Pr	Nu
0.4	0.71	1.1885
0.2	7	7.4633
0.4	7	3.7317
0.6	7	2.4878
0.2	0.71	2.3769

5. Conclusion

The flow of an incompressible viscid liquid past a linearly accelerated tilted surface with consistent mass dispersion is analysed. The influence of different factors including the Prandtl number, Schmidt number, thermal, mass Grashof numbers, and time is analysed. The following significant conclusions are listed below.

i. velocity raises when the angle of inclination (α),Schmidt number and time are decreased,
ii. velocity increases when the thermal and mass Grashof numbers raise,
iii. temperature augments with reducing the Prandtl number,
iv. concentration improves when the Schmidt number is reduced,
v. the local skin friction improves when the angle (α) , Pr , Sc increase and it decreases by increasing Gr, Gc , t_1 ,
vi. the heat transfer enhances while Pr increases,
vii. the mass transfer increases when Sc raises,

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Nomenclature

A – constant
C' – species concentration in the fluid mol. m^{-1}
m^{*} – dimensionless concentration
C_p – specific heat at constant pressure $J.kg^{-1}.K^{-1}$
D – mass diffusion coefficient $m^{2}.s^{-1}$
Gc – Grashof number (mass)
Gr – Grashof number (thermal)
g^{*} – accelerration due to gravity $m.s^{-2}$
k – thermal conductivity $J.m^{-1}.K^{-1}$
$\Pr$ – Prandtl number
Sc – Schmidt number
Q – fluid temperature closer to the plate
t_1' – time
t_1 – dimensionless time
u – fluid velocity in vertical direction $m.s^{-1}$
u_0 – velocity of the plate $m.s^{-1}$
P – dimensionless velocity
x – spatial coordinate along the plate
y' – coordinate axis normal to the plate m
y – dimensionless coordinate axis normal to the plate

Greek symbols

α – angle of inclination
β – volumetric coefficient of thermal expansion K^{-1}
β_2^{*} – volumetric coefficient of expansion with concentration K^{-1}
μ – cofficient of viscosity $Pa.s$
υ – kinematic viscosity $m^{2}.s^{-1}$
ρ – density of the fluid $kg.m^{-3}$
τ – dimensionless skin-friction $kg.m^{-1}.s^{2}$
φ – dimmensionless temperature
η – similarity parameter
$erfc$ – complementary error function

Subscripts

ω – conditions at the wall
∞ – conditions in the free stream

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