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# IMPACTS OF CHEMICAL REACTIONS ON INCLINED ISOTHERMAL VERTICAL PLATE

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An accurate parameterization of an irregular surge across a continuously propelled circulation through an endless isothermal inclined plate has been investigated in the presence of a first-degree uniform chemical reaction. Both the plate's temperature and the proximal intensity are increased systematically. To evaluate non-dimensional equations, the Laplace transform is utilized. The effect of velocity components on a range of physical parameters is investigated which include *Sc, Pr, Gr, Gc,* $\alpha$, *K* and *t*. A proportionate increase of velocity with *Gr* and *Gc* was prominent. $\tau$ and *Sh* were mathematically determined.

**Keywords:** expedited; inclined slab; heat transmission; mass transfer; chemical reaction.

## 1. Introduction

Every industrial procedure strives to convert low-cost crude ingredients into high-quality finished goods. Various operations must be carried out in a facility where various molecular changes occur, such as bringing reactants into close contact and producing a suitable environment conducive to product removal. Fluid dynamics is critical in establishing a relationship between reactor efficiency and equipment. Because of the importance of integrated thermal and mass transmission difficulties in numerous operations, they have gained significant interest. HMT research accompanying synthetic processes is of significant operational value to technologists and researchers due to its virtually regular recurrence in several sectors of research as well as technology.

Apelblat A. [1] used a 1-st level chemical process to examine the effects of mass transference. Das *et al.* [2, 3], also looked into the dominance of mass transference on surge through a spontaneously launched endless perpendicular surface with a continuous thermal flux and chemical reaction. Muthucumaraswamy R. and Janakiraman B. [4] analyzed various implications of upright undulating panels. Using a quantitative methodology, Bég O. *et al.* [5] analyzed various influences on chemically reacting combined transmission across slanted and vertical surfaces. Muthucumaraswamy *et al.* [6, 7], analyzed the influences of HMT on circulation across an advanced perpendicular panel with varied mass dispersion on a perpendicular oscillatory surface with variable temperature. Bisht *et al.* [8] investigated heat conductance on a long-term integrated

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perimeter layer flow with HMT inside a duct owing to a directed outlet. Kesavaiah *et al.* [9] analyzed radiation absorption on unstable HMT across a perpendicular panel submerged in a permeable environment with heating and vacuum. Based on the analytical findings, pictorial data for various characteristics of combined components were supplied and evaluated.

Bhattacharya [10] tested magnetohydrodynamic circulation and thermal transmission across a contracting layer under weight pressure. In the event of pull or infusion, Shivaiah and Anandrao [11] studied the effect of synthetic reactivity on an intermittent magneto-hydrodynamic absent convection circulation over a perpendicular permeable panel. The flow properties for the essential variables were demonstrated. Researchers also analyzed whether the flow patterns are impacted by the substance qualities of the circulation condition. Muthucumaraswamy *et al.* [12] analyzed the dominance of magnetism forces on thermal dispersion via an advanced isothermal straight surface. Various fundamental characteristics are investigated in connection to the impacts of velocity, temperature, and intensity characteristics.

The movement of a radiation liquid over a perpendicular slab with continual heat flux was characterized by Makinde [13] as a chemically reactive hydromagnetic unstable circulation. Barik [14] presented the mass transmission and radiation consequences on MHD circulation through an abruptly started exponential advanced sloped permeable panel. Barik *et al.* [15] also analyzed the role of thermal variables on an unstable on MHD circulation across a tilted perforated warmed surface in the vicinity of chemical interaction and viscous dispersion. Animasaun [16] investigated thermophoresis, changeable viscosity, and heat conductance in connection to spontaneous convection HMT in non-Darcian magneto-hydrodynamic diffusive Casson liquid surge with sucking and $n^{th}$ level of synthetic interaction. In [17] the influence of chemical interaction over a stretchable surface with different transmission modalities was investigated. They observed that increasing the Casson factor raises the temperature and liquid level and that the velocity barrier zone is larger. Narahari *et al.* [18] analyzed scaled thermal levels on discontinuous MHD across an unending sloping exterior amidst irradiation, heat supply, and synthetic reactivity. It was revealed that when gradient exterior temperature perimeter requirements were utilized, the fluid speed and skin resistance were reduced more than when isothermal barrier circumstances were employed. The results were directly applied to the development of synthetic treatment equipment, geothermal solutions, refrigerating mechanisms for electronic technology and solar energy collectibles. Prabhakara Reddy [19] analyzed the spontaneous convection of HMT transmission circulation inside an integrated magnetic environment of chemically sensitive and radiation-absorbing liquid.

In [20] absorbance as well as molecular exchanges on MHD motion across undulating perpendicular substrates was studied. Velocity fields, temperature, and content data were collected and visually shown. The influences of various parameters were also provided in the tables. The chemical reactivity influence on an intermittent MHD circulation across an exponentially advanced slanted surface with changeable HMT was reported by Rajput and Gaurav Kumar [21]. Khalid *et al.* [22] investigated the stability and molecular reactivity consequences on an MHD circulation of Casson liquids via a permeable media produced by a perforated shrinkage plate. In [23] the kinematic absorption on a reactive membrane with an angled magnetic field and repeated slippage was analyzed. They provided analytical approximations for various regulating variables based on velocity, temperature, and intensity characteristics. Pictorial and quantitative outputs were offered for the different variables that entered the modeled scenarios. The quantitative conclusions were compared to those of earlier investigations. It was revealed that slippage affected bounding zone circulation.

Jyotsna Rani Pattnaik *et al.* [24] analyzed the influences of radiation and mass transference on magnetohydrodynamic movement throughout a porous media across an exponentially propelled slanted surface with varying temperatures. In [25] an intermittent magneto hydrodynamic unrestricted circulation across a perforated substance in the context of heat transmission, chemical interaction, and thermal supply or drain was investigated. In [26] various influences on the hydromagnetic circulation of a dynamically interacting liquid across an exponentially propelled slanted perforated panel in the vicinity of heat retention and slow dispersion was studied. The consequences of synthetic reactivity as well as thermal liquid circulation through a geometrically expedited perpendicular slab embedded in a permeable environment with ramping wall temperature and scaled exterior intensity were explored by Kataria and Patel [27]. Propul. Usharani *et al.* [28] demonstrated the influence of an MHD flow passing over an exponentially tilted perpendicular surface with first-order molecular reactivity with adjustable material dispersion and heat emission. Temperature and floater pace were assessed using pictorial visualizations. It was fascinating to see that raising the inclination margin of a well-completed appealing region decreases the velocity curve.

Prusty and Senapati [29] investigated the uneven MHD thermal and weight transmission movement of a radiating liquid through an advanced sloped permeable surface with synthetic reactivity. In [30] unrestricted convection circulation across a perpendicular panel was investigated. At every particular time-dependent velocity, the surface proceeded rectilinearly. The fractional-order framework better exemplifies the cognitive influence and liquid circulation pattern compared to the conventional level framework. Sweta *et al.* [31] analyzed the dominance of chemical activities and thermal fluxes on magnetohydrodynamic unrestricted convective circulation across a movable upright permeable slab. The statistical synthesis of a propagating Casson liquid across an unheated inclined Riga base with highly responsive elements was investigated by Bilal Kanayo *et al.* [32]. The mathematical framework of thermal retention and synthetic reactivity influences across a slanted panel was analyzed. Bejawada and Yanala [33] analyzed the influences on an intermittent MHD thermal and material transmission circulation through an advanced sloped vertical panel. Shankar *et al.* [34] used the Galerkin finite element methodology to investigate the synthetic reactivity and viscous diffusive circulation of a magneto-nanofluid via spontaneous convection. The mathematical correlations among pace, energy, and orientation were identified utilizing Galerkin finite components.

## 2. Analysis

Consider an the unsteady circulation of a thick liquid flowing through a consistently advanced linearly slanted plate at an angle $\alpha$ from the perpendicular direction. The $x$-axis runs parallel to the vertical panel, whereas the $y$-axis runs transverse to it. When $t_2^* \le 0$, the plate and fluid exist at equal levels of temperature $N_\infty$. When $t_2^* > 0$, the plate is expedited $u = u_0\, t_2^*$ within its plane and its temperature is increased to $N_w$. The mass is transferred from the slab to the liquid. The uneven circulation is therefore regulated by the subsequent formulas under the conventional Boussinesq's approximation:

$$\frac{\partial u}{\partial t_2^*} = g\beta\cos\alpha\left(N - N_\infty\right) + g\beta^*\cos\alpha\left(F^* - F_\infty{}^*\right) + \nu\frac{\partial^2 u}{\partial y^2},$$

$$\rho C_p \frac{\partial N}{\partial t_2^*} = k\frac{\partial^2 N}{\partial y^2}, \tag{2.1}$$

$$\frac{\partial F^*}{\partial t_2^*} = D\frac{\partial^2 F^*}{\partial y^2} - K_l F^*.$$

At preliminary and periphery scenarios:

$$\begin{array}{llllll} & u = 0, & N = N_\infty, & F^* = F_\infty^* & \text{for all} & y,\, t' \le 0, \\ t' > 0: & u = u_0 t_2^*, & N = N_w, & F^* = F_w^* & \text{at} & y = 0, \\ & u \to 0 & N \to N_\infty, & F^* \to F_\infty^* & \text{as} & y \to \infty, \end{array} \tag{2.2}$$

where

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

When the relevant dimensionless variables are presented:

$$P^*=\frac{u}{(\nu u_0)^{\frac{1}{3}}},\quad t=t_2^*\left(\frac{u_0^2}{\nu}\right)^{\frac{1}{3}},\quad Y=y\left(\frac{u_0}{\nu^2}\right)^{\frac{1}{3}},\quad K=K_l\left(\frac{\nu}{u_0^2}\right)^{\frac{1}{3}},$$

$$\sigma=\frac{N-N_\infty}{N_w-N_\infty},\quad Gr=\frac{g\beta(N_w-N_\infty)}{u_0},\quad B=\frac{F^*-F_\infty^*}{F_w^*-F_\infty^*},\tag{2.3}$$

$$Gc=\frac{g\beta^*\left(F_w^*-F_\infty^*\right)}{u_0},\quad Pr=\frac{\mu C_p}{k},\quad Sc=\frac{\nu}{D},$$

Equations (2.1) and (2.4), result in

$$\frac{\partial P^*}{\partial t}=\sigma\, Gr\cos\alpha+B\ Gc\cos\alpha+\frac{\partial^2 P^*}{\partial Y^2},$$

$$\frac{\partial\sigma}{\partial t}=\frac{1}{Pr}\frac{\partial^2\sigma}{\partial Y^2},\tag{2.4}$$

$$\frac{\partial B}{\partial t}=\frac{1}{Sc}\frac{\partial^2 B}{\partial Y^2}-K\,B.$$

In non-dimensional variables, the starting and margin constraints are

$$\begin{aligned}&P^*=0,\quad \sigma=0,\quad B=0\quad \text{for all}\ \ Y,t\le 0,\\ t>0:\ \ &P^*=t,\quad \sigma=1,\quad B=1\quad \text{at}\quad Y=0,\\ &P^*\to 0,\ \ \sigma\to 0,\ B\to 0,\ \ \text{as}\quad Y\to\infty.\end{aligned}\tag{2.5}$$

## 3. Methodology of answer

The regulating formulae (2.4) are analyzed utilizing the conventional LT methodology.

$$\sigma=erfc\left(Z\sqrt{Pr}\right),\tag{3.1}$$

$$B=\frac{1}{2}\left[\exp\left(2Z\sqrt{K\,t\,Sc}\right)erfc\left(Z\sqrt{Sc}+\sqrt{K\,t}\right)+\exp\left(-2Z\sqrt{K\,t\,Sc}\right)erfc\left(Z\sqrt{Sc}-\sqrt{K\,t}\right)\right],\tag{3.2}$$

$$
\begin{aligned}
P^* = & (1-d)t\left[\left(1+2Z^2\right) erfc(Z) - \frac{2Z}{\sqrt{\pi}} e^{-Z^2}\right] + \frac{b}{K\,Sc}\, erfc(Z) + \\
& - \frac{b}{2KSc}\left[\exp\left(2Z\sqrt{K\,t\,Sc}\right) erfc\left(Z\sqrt{Sc} + \sqrt{K\,t}\right) + \right. \\
& \left. + \exp\left(-2Z\sqrt{K\,t\,Sc}\right) erfc\left(Z\sqrt{Sc} - \sqrt{K\,t}\right)\right] + \\
& - \frac{be^{ct}}{2KSc}\left[e^{2Z\sqrt{ct}}\, erfc\left(Z + \sqrt{ct}\right) + e^{-2Z\sqrt{ct}}\, erfc\left(Z - \sqrt{ct}\right)\right] + \\
& + \left(\frac{a}{1-Pr}\right) t\left[\left(1 + 2Z^2 Pr\right) erfc\left(Z\sqrt{Pr}\right) - \frac{2Z\sqrt{Pr}}{\sqrt{\pi}} e^{-Z^2 Pr}\right] + \\
& - \frac{b\,e^{ct}}{2KSc}\left[\exp\left(2Z\sqrt{Sc\,L_1}\right) erfc\left(Z\sqrt{Sc} + \sqrt{L_1}\right) + \right. \\
& \left. + \exp\left(-2Z\sqrt{Sc\,L_1}\right) erfc\left(Z\sqrt{Sc} - \sqrt{L_1}\right)\right],
\end{aligned}
\tag{3.3}
$$

where $Z = \dfrac{Y}{2\sqrt{t}}$, $a = Gr\cos\alpha$, $b = Gc\cos\alpha$, $c = \dfrac{KSc}{1-Sc}$, $d = \dfrac{a}{1-Pr}$, $L_1 = (K+d)t$.

**Skin-friction ($\tau$)**

According to research, the non-dimensional plate friction factor is $\tau = -\left[\dfrac{\partial P^*}{\partial y}\right]_{y=0}$,

$$
\begin{aligned}
\tau = & \frac{2(1-d)\sqrt{t}}{\sqrt{\pi}} + \frac{b}{K\,Sc\sqrt{\pi t}} - \frac{b\,e^{ct}}{4K\,Sc\sqrt{\pi t}}\left[4\,e^{ct} - 2\sqrt{\pi\,ct}\left(erfc\left(\sqrt{ct}\right) - erfc\left(-\sqrt{ct}\right)\right)\right] + \\
& + \frac{2\sqrt{Pr}}{\sqrt{\pi t}}\left(\frac{a\,t}{1-Pr}\right) - \frac{b}{2K\sqrt{\pi Sc\,t}}\left[2\,e^{-K\,t} - \sqrt{\pi K\,t}\left(erfc\left(\sqrt{Kt}\right) - erfc\left(-\sqrt{Kt}\right)\right)\right] + \\
& - \frac{b\,e^{ct}}{2K\sqrt{\pi Sc\,t}}\left[2\,e^{-L_2} - \sqrt{L_2\pi}\left(erfc\left(\sqrt{L_2}\right) - erfc\left(-\sqrt{L_2}\right)\right)\right],
\end{aligned}
\tag{3.4}
$$

where $L_2 = (K+c)t$.

**Sherwood number** ($Sh$)

$Sh$ is given by $Sh = -\left[\dfrac{dB}{dy}\right]_{y=0}$,

$$
Sh = \sqrt{\frac{Sc}{\pi t}}\, e^{-K\,t} - \frac{\sqrt{K\,Sc}}{2}\left[\left(erfc\left(\sqrt{Kt}\right) - erfc\left(-\sqrt{Kt}\right)\right)\right]. \tag{3.5}
$$

**Nusselt number** ( $Nu$ )

$Nu$ is given by $Nu = -\left[\frac{d\sigma}{dy}\right]_{y=0}$ ,

$$Nu = \frac{\sqrt{Pr}}{\sqrt{\pi t}}. \tag{3.6}$$

## 4. Results and discussion

The scrutiny of different models that follows is planned out to highlight the impact of the different factors on flow attributes. We have displayed the temperature distribution, concentration, and non-dimensional velocity components for several estimates of $Sc$, $Pr$, $Gr$, $Gc$, $\alpha$, $K$ and $t$ in Graphs (1) to (13).

Figures 1 and 2 show the impact of velocity on a range of Schmidt numbers $Sc$ at an inclination angle of *45°* and *60°*, respectively. It is clearly stated that the Schmidt number $Sc$ is reduced, which causes an increase in velocity. Figure 3 shows various contours for different $Gc$ values. It shows that when $Gc$ decreases, velocity also increases. Also, the impact of velocity for various thermal Grashof numbers is revealed in Fig. 4. When $Gc$ decreases, velocity augments.

The velocity curve is depicted in Fig.5 for various tilt degrees $\alpha$. It turns out that the angle $\alpha$ decreased while the velocity increased. Information is shown in Figures 6 and 7 for various times when the tilt angle is *45°* and *60°*, respectively. It has been established that velocity increases with time.

Figures 8 and 9 demonstrate velocity patterns for various chemical process variables at various inclinations. Velocity augments in an inversely proportional manner along with the variable $K$. The pattern for different combinations of $Gr$ and $Gc$ is revealed in Fig.10. It has been demonstrated that the Grashof numbers cause an increase in velocity.

The influence of the simulation contours at varied $Sc$ is shown in Fig.11. In the field, the concentration influence is strong. In all of the profiles, the concentration declines monotonically from the exterior to a nil parameter distant in the unrestrained surge. As the Schmidt number falls, an enhancement in the wall focus is observed. The impact of the different contours is revealed in Fig.12 for different $K$ values. A decrease in wall concentration has occurred as a result of a chemical reaction.

The temperature distribution shown in Fig.13 reduces as $Pr$ enhances, which is in agreement with the observation of the inverse proportionality of TBL with $Pr$. As the Prandtl number grows, so does the rate of heat transmission. As $Pr$ rises, the boundary layer edge is reached more quickly. As seen in Fig. 13, when Tf associated with air $\left(Pr = 0.71\right)$ is higher than if associated with water $\left(Pr = 0.7\right)$.

Table 1 shows the effects of local skin friction for a variety of parameters, including the Prandtl, Schmidt numbers, temperature, mass, and inclination angles. The Prandtl and Schmidt values, as well as $\alpha$, all contribute to an augmentation in skin friction.

Table 2 shows how the physical variables $Sc$ and $t$ affect the Sherwood number. It is visible that when $Sh$ rises so does $Sc$. So, when, the mass transfer increases $Sc$ goes up.

The Nusselt numbers $Nu$ are shown in Table 3 for various physical parameters $Pr$ and time. When the Prandtl number is raised, $Nu$ also rises. In the light of this, we may say that heat transport is increasing with a rise in $Pr$.

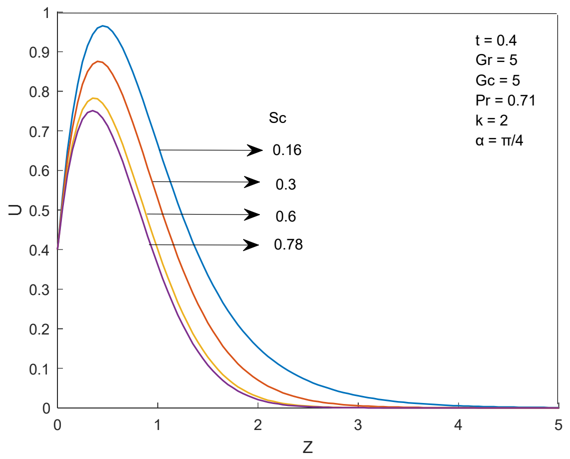


Fig.1. Characteristics for various numbers of *Sc* .

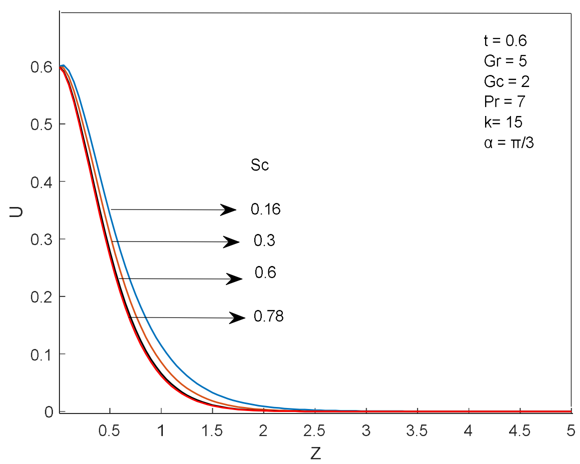


Fig.2. Characteristics for various numbers of *Sc* .

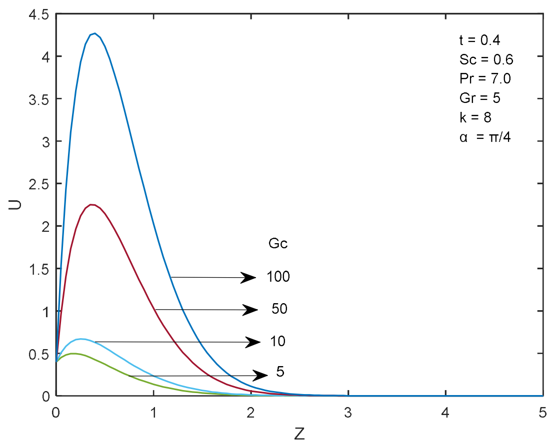


Fig.3. Characteristics for various numbers of *Gc* .

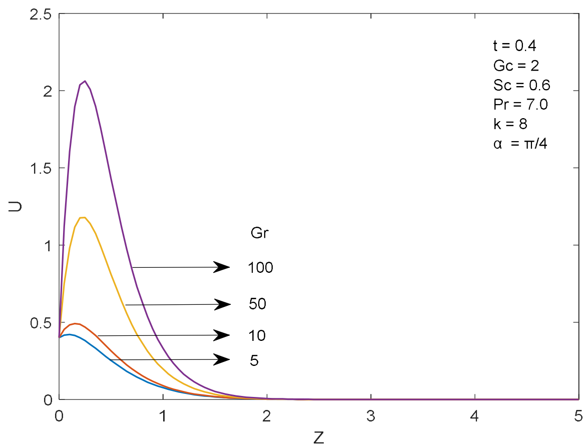


Fig.4. Velocity patterns for various numbers of *Gr* .

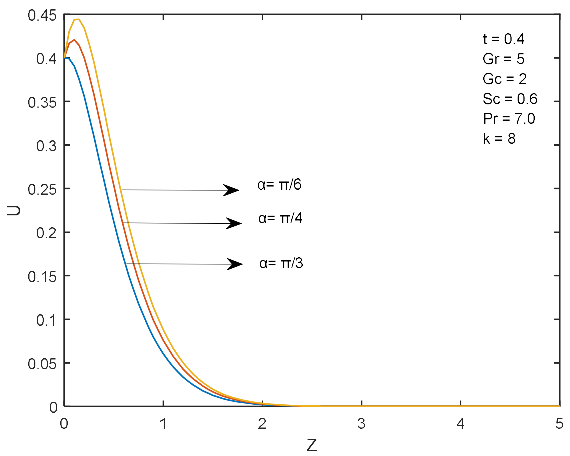


Fig.5. Velocity curves for various numbers of α .

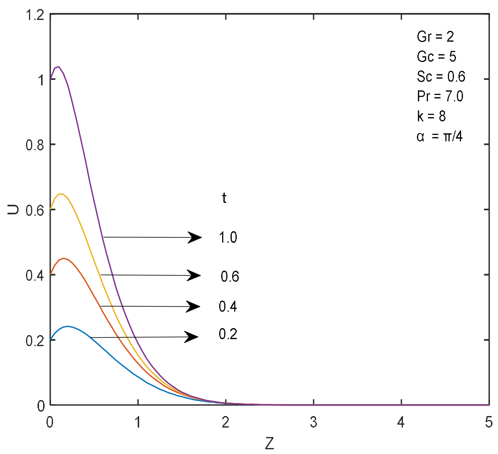


Fig.6. Velocity patterns for various numbers of *t* .

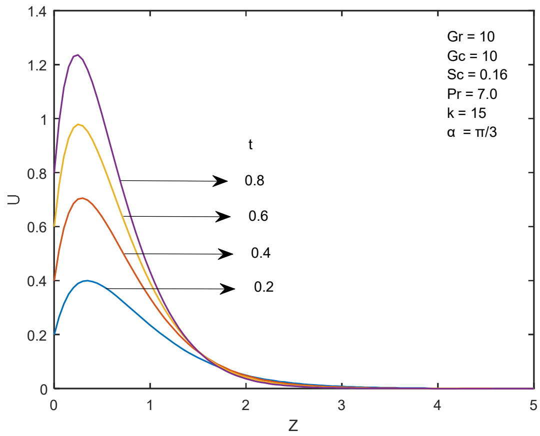


Fig.7. Velocity distributions for various numbers of $t$ .

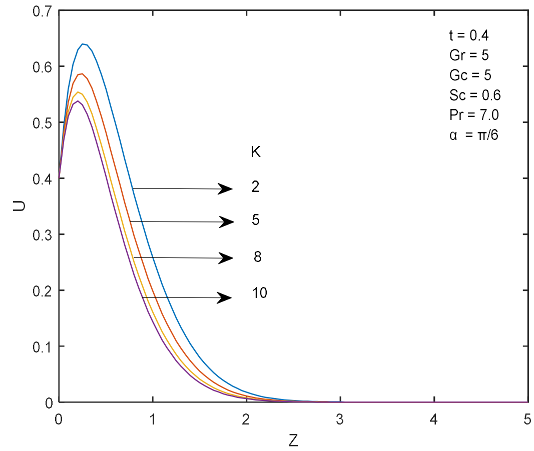


Fig.8. Velocity patterns for various numbers of $K$ .

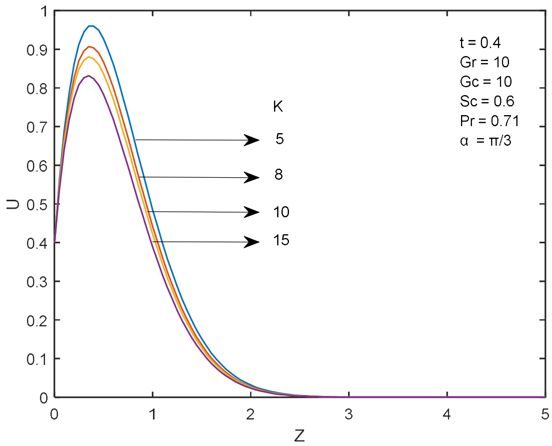


Fig.9. Velocity patterns for various numbers of $K$ .

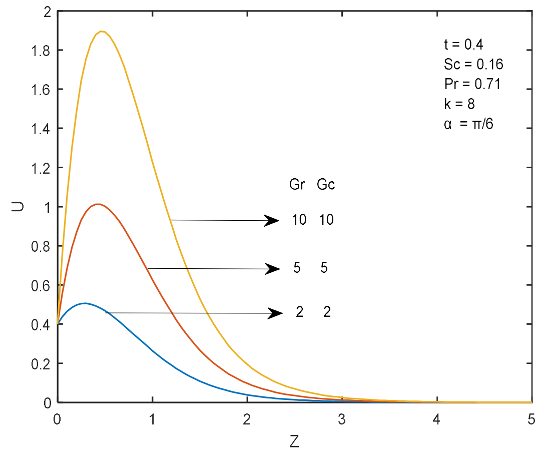


Fig.10. Velocity characteristics for various numbers of $Gr$ and $Gc$ .

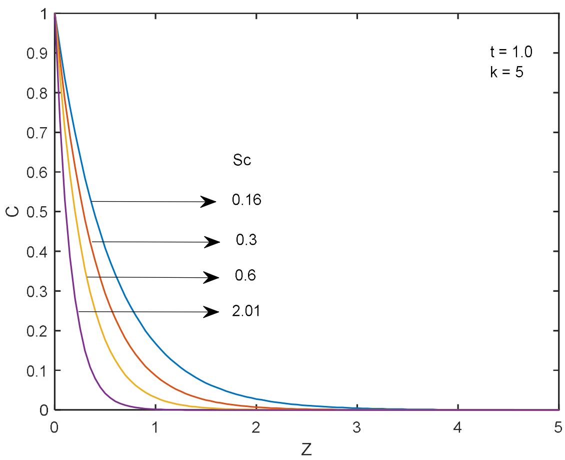


Fig.11. Concentration characteristics for various numbers of $Sc$ .

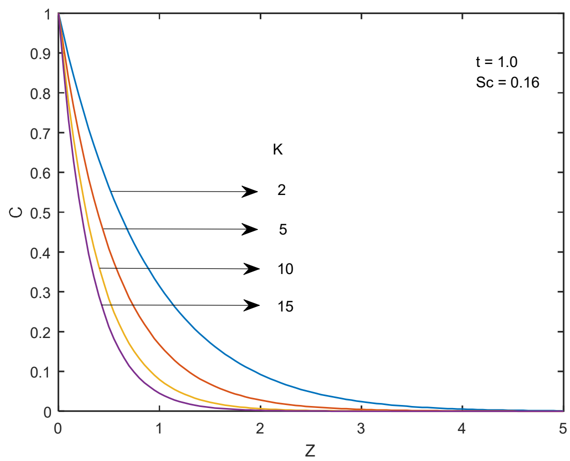


Fig.12. Concentration levels for different numbers of $K$ .

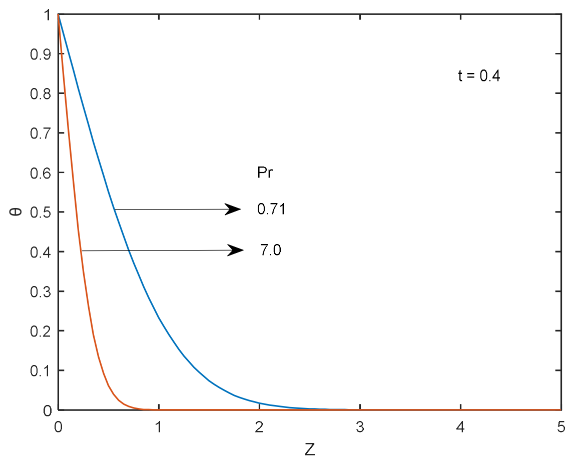


Fig.13. Temperature distributions for different numbers of *Pr*.

Table 1. Skin-friction for varying factors.

| α | *t* | Pr | *Gr* | *Gc* | *Sc* | *K* | τ |
|---|---|---|---|---|---|---|---|
| 300 | 0.2 | 0.71 | 2 | 2 | 0.16 | 2 | -20.2320 |
| 450 | 0.2 | 0.71 | 2 | 2 | 0.6 | 2 | -19.3501 |
| 300 | 0.2 | 0.71 | 2 | 5 | 0.6 | 2 | -45.6545 |
| 600 | 0.2 | 0.71 | 5 | 5 | 0.6 | 2 | -36.1436 |
| 300 | 0.2 | 0.71 | 2 | 2 | 0.3 | 2 | -19.2465 |
| 450 | 0.4 | 0.71 | 2 | 5 | 0.16 | 5 | -22.7130 |
| 600 | 0.4 | 0.71 | 2 | 2 | 0.6 | 2 | -19.7728 |
| 600 | 0.6 | 0.71 | 2 | 5 | 0.3 | 5 | -34.4350 |
| 300 | 0.8 | 0.71 | 5 | 2 | 0.6 | 5 | -46.1922 |
| 450 | 0.6 | 0.71 | 2 | 2 | 0.3 | 5 | -20.9541 |

Table 2. The Sherwood quantity for various factors.

| *t* | *Sc* | *Sh* |
|---|---|---|
| 0.6 | 0.3 | 1.7321 |
| 0.4 | 0.3 | 1.7329 |
| 0.2 | 0.3 | 1.7468 |
| 0.6 | 0.6 | 2.446 |
| 0.4 | 0.6 | 2.4507 |
| 0.2 | 0.6 | 2.4703 |
| 0.6 | 2.01 | 4.4835 |
| 0.4 | 2.01 | 4.4855 |
| 0.2 | 2.01 | 4.5214 |

Table 3. Nusselt quantity for various factors.

| *t* | *Pr* | *Nu* |
|---|---|---|
| 0.2 | 0.71 | 1.0630 |
| 0.4 | 0.71 | 0.7517 |
| 0.6 | 0.71 | 0.6137 |
| 0.6 | 7.0 | 1.9271 |
| 0.4 | 7.0 | 2.3602 |
| 0.2 | 7.0 | 3.3378 |
| 0.8 | 7.0 | 1.6689 |
| 1 | 7.0 | 1.4927 |

## 5. Conclusion

We have examined the precise solution of the 1st-order chemical process where an unstable circulation passes a linearly accelerated flow through an endless isothermal inclined plate. Several factors, including $Sc, Gr, Gc, \alpha, K$ and $t$, along with the influence of $v$, $T$ and intensity are explored. The findings are as follows:

- When $\alpha$, $Sc$ and duration are reduced, the velocity increases.
- It has been discovered that velocity augments along with the $Gr, Gc$ and $t$.
- $Sc$ and chemical reactivity variable decrease resulting in a rise in wall intensity.
- As $t$ goes on, the plate's temperature rises.

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**Nomenclature**

| | |
|---|---|
| $A$ | – constant |
| $erfc$ | – complementary error function |
| $B, C$ | – dimensionless concentration |
| $C_p$ | – specific heat at constant pressure $J \cdot kg^{-1} \cdot K^{-1}$ |
| $D$ | – mass diffusion coefficient $m^2 \cdot s^{-1}$ |
| $F^*$ | – species concentration in the fluid $mol\ m^{-1}$ |
| $Gc$ | – Grashof number (mass) |
| $Gr$ | – Grashof number ( thermal) |
| $g$ | – accelerration due to gravity $m \cdot s^{-2}$ |
| $K$ | – chemical reaction |
| $k$ | – thermal conductivity $J \cdot m^{-1} \cdot K^{-1}$ |
| $Pr$ | – Prandtl number |
| $Sc$ | – Schmidt number |
| $Sh$ | – Sherwood number |
| $N, T$ | – fluid temperature closer to the plate |
| $Nu$ | – Nusselt number |
| $t_1$ | – dimensionless time |
| $t_2^*$ | – time |
| $U, P^*$ | – dimensionless velocity |
| $u$ | – fluid velocity in vertical direction $m \cdot s^{-1}$ |
| $u_0$ | – velocity of the plate $m \cdot s^{-1}$ |
| $x$ | – spatial coordinate along the plate |
| $y$ | – dimensionless coordinate axis normal to the plate |
| $y'$ | – coordinate axis normal to the plate $m$ |

**Greek symbols**

| | |
|---|---|
| $\alpha$ | – angle of inclination |
| $\beta$ | – volumetric coefficient of thermal expansion $K^{-1}$ |
| $\beta_2^*$ | – volumetric coefficient of expansion with concentration $K^{-1}$ |
| $\eta, Z$ | – similarity parameter |

$\mu$ – cofficient of viscosity $Pa \cdot s$

$\upsilon$ – kinematic viscosity $m^2 \cdot s^{-1}$

$\rho$ – density of the fluid $kg \cdot m^{-3}$

$\sigma, \theta$ – dimmensionless temperature

$\tau$ – dimensionless skin-friction $kg \cdot m^{-1} \cdot s^2$

**Subscripts**

$w$ – conditions at the wall

$\infty$ – conditions in the free stream

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