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CONVECTIVE HEAT AND MASS TRANSFER EFFECTS OF ROTATION ON PARABOLIC FLOW PAST AN ACCELERATED ISOTHERMAL VERTICAL PLATE IN THE PRESENCE OF CHEMICAL REACTION OF FIRST ORDER

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Abstract

A diagnostic philosophy of rotational impacts on unsteady parabolic flow past of an impenetrable and electrically leading liquid past a consistently quickened boundless isothermal perpendicular plate within sight of a first-order chemical response with the absence of magnetohydrodynamic has been accounted for in the examination. All the while, the plate temperature is raised to T_∞ and concentration level close to the plate is occupied with time. The dimensionless differential condition is resolved with the help of the Laplace-change strategy. The temperature and velocity concentration profiles have been perused for various actual boundaries, first-order chemical response boundary, mass Grashof range, warm Grashof range, Schmidt number, Prandtl number, and time t. 2-D figures have been

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processed in MATLAB R2019. It is seen that the predominant velocity increases with extending assessment of warm Grashof or mass Grashof range. It is similarly observed that the velocity increases with lessening rotational limit. The pattern is essentially exchanged concerning the chemical reaction limit.

Nomenclature

A	Constants
C	Dimensionless concentration
C_p	Specific heat at constant pressure
C'	Species concentration in the fluid
C'_w	Wall concentration in the fluid
C'_∞	Concentration in the fluid far away from the plate
D	Mass diffusion coefficient
Gc	Mass Grashof number
Gr	Thermal Grashof number
g	Acceleration due to gravity
k	Thermal conductivity
K	Chemical reaction parameter
Pr	Prandtl number
Sc	Schmidt number
T	Temperature of the fluid near the plate
T_w	Temperature of the plate
T_∞	Temperature of the fluid far away from the plate
t	Dimensionless time
t'	Time

u	Velocity of the fluid in the x-direction
u_0	Velocity of the plate
x	Spatial coordinate along with the plate
y	Coordinate axis normal to the plate
Z	Dimensionless coordinate axis normal to the plate

Greek symbols

β	Volumetric coefficient of thermal expansion
β^*	Volumetric coefficient of expansion with concentration
Ω	Rotational parameter
μ	Coefficient of viscosity
ν	Kinematic viscosity
σ	Electrical conductivity
ρ	Density of the fluid
τ	Dimensionless skin-friction
θ	Dimensionless temperature
η	Similarity parameter
$erfc$	Complementary error function

Subscripts

w	Conditions at the wall
∞	Free stream conditions

1. Introduction

A chemical reaction in chemical reaction engineering deals with the chemically reactive system of engineering significance. Its application is much needed in the development of new and improvement on existing methodologies. The discipline quantifies the interaction between the transport phenomenon and reaction kinematics. One can find that the industries with the chemical process are designed to yield a good product economically from various starting materials through a succession of treatment steps. The main application of chemical reaction engineering includes ethylene products, typical chemical process, smog modelling, reducing smog by the catalytic converter, considerable scale growth of stem cells, pharmacokinetics, fuel cells, microchannel reactors [1]. A chemical reaction is classified based on the state of reactants and products. They are heterogeneous and homogeneous responses. It is also ranked based on the presence of catalytic chemical reaction. A chemical reaction takes place in concentration of species only as the chemical reaction rate depends on the concentration of reactants. Usually, it enhances as the concentration of reactants occurs higher in oxygen than in air at equal pressure. Coupled heat and mass transfer finds a wide variety of applications in engineering applications such as grain storage installation, chemical catalytic reactors and chemical pollutants in plants, diffusion of medicine in blood veins, and migration [2].

Das et al. examined and gave a pictorial representation of transient free convective stream past a limitless vertical plate with temperature variation [3]. Hossain and Takhar sorted out graphically the radiation impacts on blended convection along with a vertical plate with uniform surface temperature [4]. Mass exchange consequences for the stream past a quickened perpendicular plate with consistent warmth transition were studied by Jha et al. [5]. Natural convection on moving vertical plate with the chemical reaction concentrated by Muthucumaraswamy and Ganesan [6]. Muthucumaraswamy and Radhakrishnan gave a point-by-point report on first request substance response impacts on thin stream past a quickened vertical plate with variable temperature and mass dispersion [7]. Muthucumaraswamy and Amutha examined the diffusion of responsive species and warmth move consequences for a quickened vertical plate with uniform warmth motion [8]. Muthucumaraswamy and Velmurugan logically studied heat and mass transfer effects on flow past parabolic started isothermal vertical plate in the presence of chemical reaction of the first order [9]. Theoretical study of heat transfer effects on flow past a parabolic started vertical plate in the presence of chemical reaction of the first order is done by Muthucumaraswamy and Velmurugan [10]. Selvaraj et al. graphically explained MHD-parabolic flow past an accelerated isothermal vertical plate with heat and mass diffusion in the presence of rotation [11]. Maran et al. gave clear ideology on first order chemical response impact of MHD flow past an infinite vertical plate flow past of exponentially with variable mass diffusion and thermal radiation [12]. An algorithm for generating some inverse Laplace transform of exponential form is provided by Hetnarski. A calculation for producing some inverse Laplace transform of exponential form is given [13]. The object of the present study is analyzed with illustrative parabolic flow past an isothermal perpendicular plate with heat and mass scattering in the presence of rotation and first chemical substance response. The mathematical model from the Navier condition has been lessened to a coupled partial differential equation for velocity concentration, temperature using Boussinesq's approximation.

2. Mathematical Formulation

Consider an unsteady two-dimensional boundary layer of parabolic flow past of stream incompressible, electrically conducting rotating fluid past a moving vertical plate in the presence of a first-order chemical reaction considered. At first, the temperature and focus close to the plate are thought to be T'_∞ and C'_∞. At time $t' > 0$, the plate begins moving with speed $u = (u_0 t')^2$ in its plane, and the temperature from the plate is raised to T_w, and the concentration level close to the plate is made to rise directly with time. The reaction is required to happen absolutely inside the stream. It was seen that the plate is having the plane $z' = 0$ is of endless degrees. All the genuine totals depend essentially on z' and t'. By then, the unsteady flow is ruled by the standard Boussinesq's measure in dimensionless structure as follows:

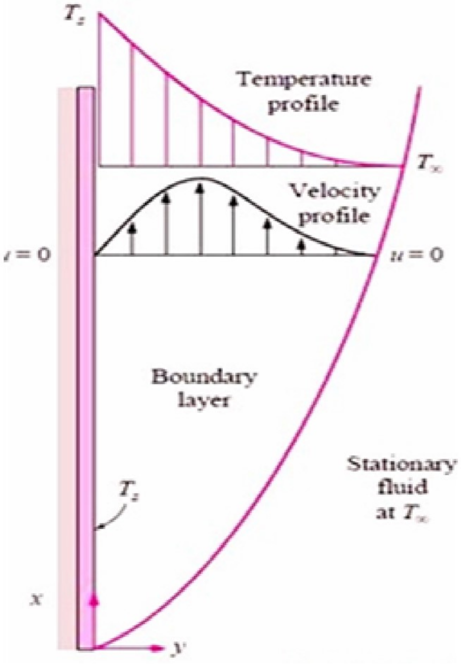

Figure 1. Boundary layer with velocity and temperature profiles.

$$\frac{\partial U}{\partial t} - 2\Omega V = Gr\theta + GcC + \frac{\partial^2 U}{\partial Z^2}, \tag{1}$$

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

$$\frac{\partial \theta}{\partial t} = \frac{1}{Pr}\frac{\partial^2 \theta}{\partial Z^2}, \tag{3}$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial Z^2} - KC. \tag{4}$$

The first two equations represent the dominant velocity profiles obtained from Boussinesq's measure. From the above equations, the terms $2\Omega V$ and $2\Omega U$ clarify the flow past executed in the presence of rotation since the negative sign indicates chemical concentration.

With the accompanying starting and limit conditions:

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

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

$$u \to 0, \quad T' \to T'_\infty, \quad C' \to C'_\infty \text{ at } y \to \infty. \tag{5}$$

On suggesting the subsequent dimensionless quantities:

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

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

$$Gc = \frac{g\beta^*(C'_w - C'_\infty)}{u_0}, \quad Pr = \frac{\mu C_p}{k},$$

$$K = K_l\left(\frac{v}{u_0^2}\right)^{\frac{1}{3}}, \quad Sc = \frac{v}{D}. \tag{6}$$

On suggesting nondimensional parameters, Prandtl number, Schmidt number, mass Grashof number, thermal Grashof number ratios are given in equation (6). Prandtl number is the ratio between momentum and thermal diffusivity, and it is significant to measure the relative value of heat transfer and transfer in the thermal velocity layer. Grashof number is the heat transfer that measures the ratio between buoyancy to viscous one. Therefore, it is applicable to measure the fluid, showing how dominant the buoyancy force is, which is highly responsible for the convection compared with the viscous force. Final one Schmidt is the measure of the ratio between momentum to mass diffusivity and to analyze the diffusion coefficient. The first-order chemical reaction on flow past parabolic in the presence of rotation is depicted by coupled partial differential equations (1) and (2) and solved using complex velocity $q = u + iv$ and presented as a single equation

(7). This equation (7) will figure out the complete analysis of the velocity profiles:

$$\frac{\partial q}{\partial t} = Gr\theta + GcC + \frac{\partial^2 q}{\partial Z^2} - mq. \tag{7}$$

The accompanying starting and limit conditions in dimensionless quantities are as follows:

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

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

$$q \to 0, \quad \theta \to 0, \quad C \to 0, \quad Z \to 0. \tag{8}$$

The derived partial differential equation (7) is solved using the boundary condition (8) where $m = (2i\Omega)$.

3. Derived Equation

Equation (7) is solved using condition (8) with the Laplace change strategy derived using an algorithm for generating some inverse Laplace transform. Thus, the solutions are in terms of exponential and complementary functions:

$$q = 2\Bigg[\frac{(\eta^2 + (2i\Omega)t)t}{4(2i\Omega)}[e^{2\eta}\sqrt{(2i\Omega)t}\; erfc(\eta + \sqrt{(2i\Omega)t})$$

$$+ e^{-2\eta}\sqrt{(2i\Omega)t}\; erfc(\eta - \sqrt{(2i\Omega)t})]$$

$$+ \frac{\eta\sqrt{t}(1 - 4(2i\Omega)t)}{8(2i\Omega)^{\frac{3}{2}}}[e^{-2\eta}\sqrt{(2i\Omega)t}\; erfc(\eta - \sqrt{(2i\Omega)t})$$

$$- e^{2\eta}\sqrt{(2i\Omega)t}\; erfc(\eta + \sqrt{(2i\Omega)t})] - \frac{\eta t}{2m\sqrt{\pi}} e^{-(\eta^2 + (2i\Omega)t)}\Bigg]$$

$$+ \left[\frac{Gr}{a(1 - Pr)} + \frac{Gc}{b(1 - Sc)}\right]\frac{1}{2}[e^{2\eta}\sqrt{(2i\Omega)t}\; erfc(\eta + \sqrt{(2i\Omega)t})$$

$$+ e^{-2\eta}\sqrt{(2i\Omega)t}\ erfc(\eta - \sqrt{(2i\Omega)t}\,)]$$

$$- \frac{Gr}{a(1-Pr)}\left[\frac{e^{at}}{2}[e^{2\eta}\sqrt{(2i\Omega + a)t}\ erfc(\eta + \sqrt{(2i\Omega + a)t}\,)]\right.$$

$$\left. + [e^{2\eta}\sqrt{(2i\Omega - a)t}\ erfc(\eta + \sqrt{(2i\Omega - a)t}\,)]\right]$$

$$- \frac{Gc}{b(1-Sc)}\left[\frac{e^{bt}}{2}[e^{2\eta}\sqrt{(2i\Omega + b)t}\ erfc(\eta + \sqrt{(2i\Omega + b)t}\,)]\right.$$

$$\left. + [e^{2\eta}\sqrt{(2i\Omega - b)t}\ erfc(\eta + \sqrt{(2i\Omega - b)t}\,)]\right]$$

$$- \frac{Gr}{a(1-Pr)}\,erfc(\eta\sqrt{Pr})$$

$$+ \frac{Gr}{a(1-Pr)}\left[\frac{e^{at}}{2}[e^{2\eta}\sqrt{Prat}\ erfc(\eta\sqrt{Pr} + \sqrt{at}\,)]\right.$$

$$\left. + [e^{-2\eta}\sqrt{Prat}\ erfc(\eta\sqrt{Pr} - \sqrt{at}\,)]\right]$$

$$- \frac{Gc}{2b(1-Sc)}[[e^{2\eta}\sqrt{ScKt}\ erfc(\eta\sqrt{Sc} + \sqrt{(Kt)}\,]$$

$$+ e^{-2\eta}\sqrt{ScKt}\ erfc(\eta\sqrt{Sc} - \sqrt{(Kt)}\,]$$

$$+ \frac{Gc}{b(1-Sc)}\left[\frac{e^{bt}}{2}[e^{2\eta}\sqrt{Sc(b+K)t}\ erfc(\eta\sqrt{Sc} + \sqrt{(K+b)t}\,)]\right.$$

$$\left. + e^{-2\eta}\sqrt{Sc(b+K)t}\ erfc(\eta\sqrt{Sc} - \sqrt{(K+b)t}\,)\right], \tag{9}$$

$$\theta = erfc(\eta\sqrt{Pr}\,), \tag{10}$$

$$C = \frac{1}{2}[e^{2\eta\sqrt{KtSc}} erfc(\eta\sqrt{Sc} + \sqrt{Kt}) + e^{-2\eta\sqrt{KtSc}} erfc(\eta\sqrt{Sc} - \sqrt{Kt})], \quad (11)$$

where $a = \frac{2i\Omega}{Pr - 1}$ and $b = \frac{2i\Omega - KSc}{Sc - 1} \eta = \frac{Z}{2\sqrt{t}} \eta$ (similarity parameter),

$$erfc(a + ib) = erf(a) + \frac{\exp(-a^2)}{2a\pi}[1 - \cos(2ab) + i\sin(2ab)]$$

$$+ \frac{2\exp(-a^2)}{\pi} \sum_{n=1}^{\infty} \frac{\exp(-\eta^2/4)}{\eta^2 + 4a^2}[f_n(a, b) + ig_n(a, b)]$$

$$+ \varepsilon(a, b). \quad (12)$$

θ and C represent the obtained final results of temperature and concentration profiles. This equation is processed with different inputs for comparing the results. While handling the velocity profile q, the complementary error function is in terms imaginary and such an equation is solved using above formula (12).

4. Results and Interpretation

For a physical understanding of the problem, numerical estimation was carried out using Tables 1 and 2 for different parameters such as Grashof number-thermal, mass Grashof number, chemical reaction, rotational parameter, Prandtl number, Schmidt number, and time. Finally, the obtained equation is modulated using assigned inputs in Matlab-R2019, and exported results are given.

Figures 2 and 3 illustrate primary and secondary velocity profiles for different values of *Gr* and *Gc*. The pattern reveals velocity increases with a gradual rise in Grashof range. Figure 4 describes the secondary velocity profile for different values of Ω and shows a slightly growing estimation concerning rotational parameters. The study investigated the absence of magnetohydrodynamic in addition to a chemical reaction.

Table 1. Numerical values for estimating velocity profiles

Non-dimensional parameter	Figure 2	Figure 3	Figure 4
	Primary velocity - *Gr* and *Gc*	Secondary velocity - *Gr* and *Gc*	Secondary velocity - Ω
Gr	5, 5, 10	5, 5, 10	10
Gc	5, 10, 10	5, 10, 10	10
K	8	8	8
Sc	2.01	2.01	2.01
Pr	7	7	7
t	0.2	0.1	0.1
Ω	0.1	0.1	0.5, 1, 1.5
Inference	An increase in velocity leads to a rise in *Gr* and *Gc*	An increase in velocity leads to a rise in *Gr* and *Gc*	Increase in velocity concerning Ω

Table 2. Numerical values for estimating temperature and concentration profiles

Non-dimensional parameter	Figure 5	Figure 6	Figure 7
	Concentration profile-*K*	Concentration profile-*Sc*	Temperature profile-*Pr*
K	0.2, 2, 5	0.2	-
Sc	2.01	0.16, 0.3, 0.6, 2.01	2.01
Pr	-	-	7.0, 0.71
t	0.6	0.2	0.2
Inference	Rise in concentration with a decline in the chemical reaction	Increase with lowering estimation of Schmidt range	Temperature increases with lowering the value of *Pr*

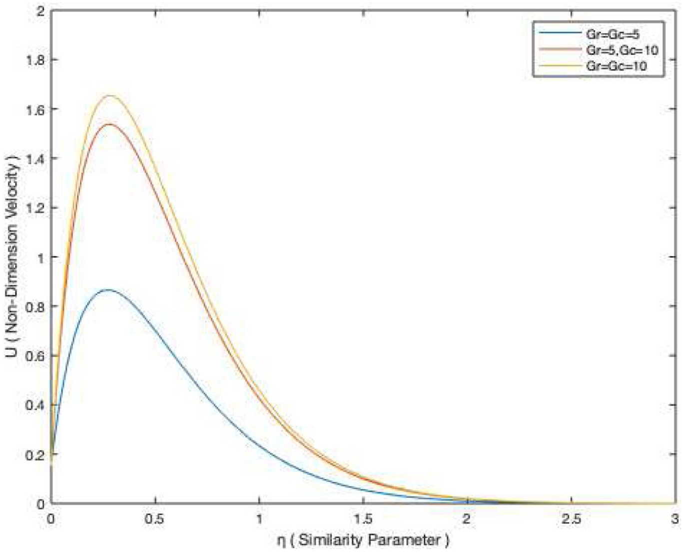

Figure 2. Primary velocity for different *Gr* and *Gc*.

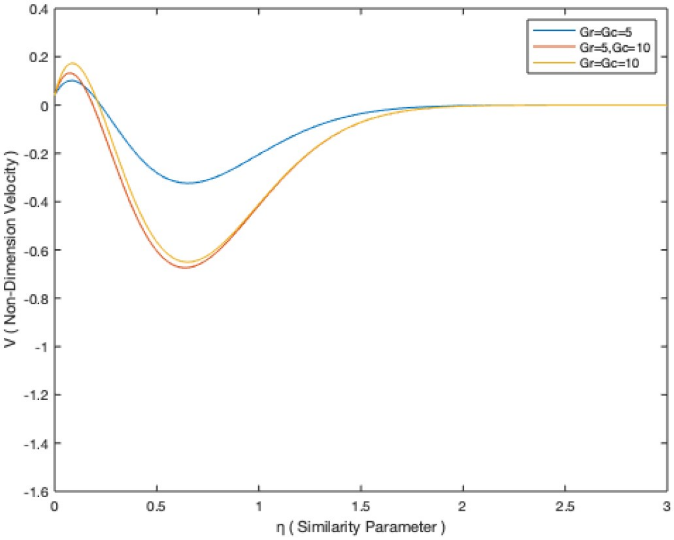

Figure 3. Secondary velocity for different *Gr* and *Gc*.

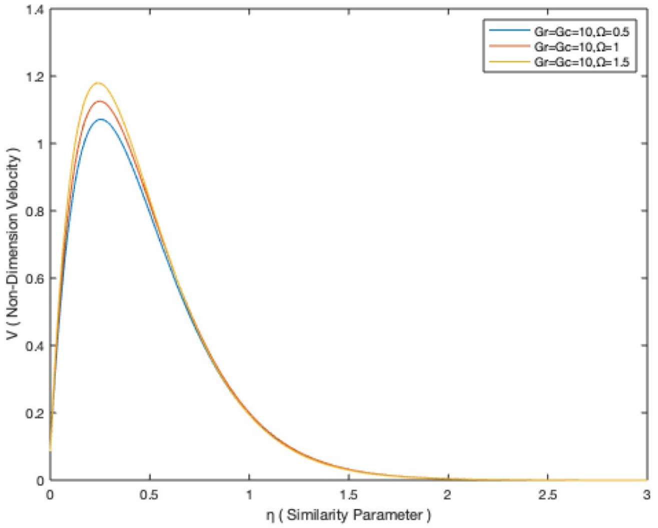

Figure 4. Secondary velocity for different Ω.

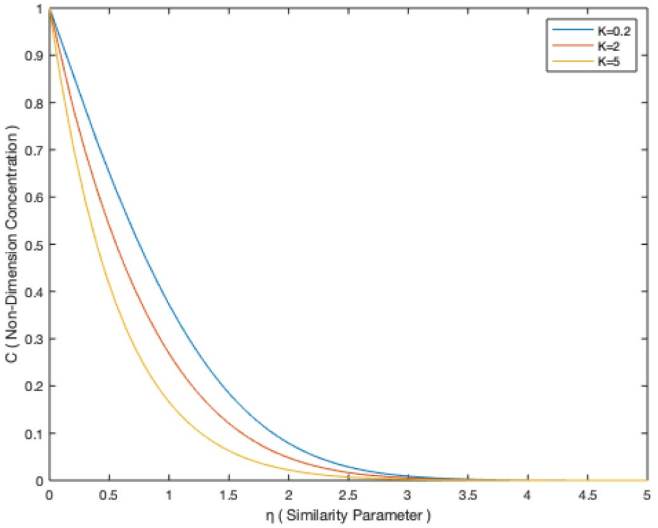

Figure 5. Concentration profile for different *K*.

Figures 5 and 6 illustrate the concentration profiles for different values of *K* and *Sc*. The pattern reveals a rise in concentration with lowering estimation of the synthetic response parameter. The chemical reaction plays a significant role in concentration, and chemical species is considered as hydrogen (H_2), helium (He), water vapor (H_2O), ethylbenzene $(C_6H_5CH_2CH_3)$, and concentration increments with lessening values of the Schmidt number. Figure 7 depicts the effect of the Prandtl number. It is seen that the temperature increases with the lessening value of the Prandtl number.

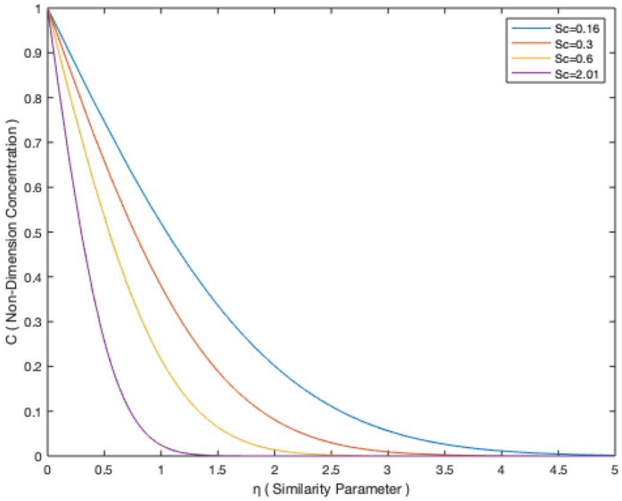

Figure 6. Concentration profile for different *Sc*.

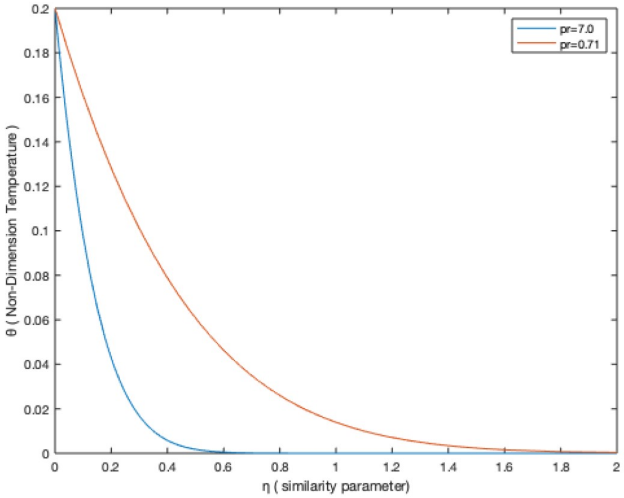

Figure 7. Temperature profile for different *Pr*.

5. Conclusion

The examination reveals the nonappearance of MHD-illustrative stream past a stimulated isothermal vertical plate with first chemical substance reaction in the presence of rotation has been analytically examined. The course of action of the dimensionless condition is satisfied by the Laplace change strategy. The limits considered are mass Grashof number, Prandtl number, Schmidt number, substance reaction limit and rotational limit, warm Grashof number, *t*. The results are enlisted below:

- It is found that the pattern displays the velocity rising with the flourishing estimation of *Gr* and *Gc*.
- It is found that the illustrative concentration exhibits an upward push in attention with decreasing estimation of the synthetic response parameter.
- It is viewed that the temperature will increase with the lessening of the Prandtl number.

The example traded as for the rotational boundary.

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