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Abstract : Two-dimensional MHD mixed convection boundary layer flow of heat and mass transfer stagnation-point flow of a non-Newtonian power-law nanofluid towards a stretching surface with thermal radiation and heat source/sink in the presence of viscous dissipation and variable suction/injection is investigated numerically. The governing partial differential equations are converted into nonlinear, ordinary, and coupled differential equations and are solved using bvp4c Matlab solver. The numerical results are compared with the published data and are found to be in good agreement.

Keywords: MHD, Mixed convection, Heat and Mass Transfer, Viscous Dissipation, Heat Source/Sink, Suction/injection.

Introduction

square enclosure with differentially heated side walls. Uddin et al. [18] studied the steady two-dimensional non-isothermal boundary layer flow from a heated horizontal surface which is embedded in a porous medium saturated with a non-Newtonian power-law nanofluid. Niu et al [19] concluded that increase of the slip length always results in larger flow rate of the nanofluid and the heat transfer rate of the nanofluid in the microtube can be enhanced due to the non-Newtonian rheology and slip boundary effects. Nadeem and Saleem [20] studied the rotating non-Newtonian nanofluid on a rotating cone. Mahdy and Chamkha [21] studied the heat transfer and fluid flow of a non-Newtonian nanofluid over an unsteady contracting cylinder employing Buongiorno’s model. Khan and Pop [22] investigated the boundary-layer flow of a nanofluid past a stretching sheet.

The effect of heat source/sink is very important in cooling process industries and radiative heat transfer in which heat is transmitted from one point to another without heating the intervening medium has been found very important in the design of reliable equipment, nuclear plants, gas turbines, and various propulsion devices for aircraft, missiles, satellites, and space vehicles. Haile and Shankar [23] studied the heat and mass transfer in the boundary-layer flow of unsteady viscous nanofluid along a vertical stretching sheet in the presence of magnetic field, thermal radiation, heat generation, and chemical reaction. Gangadhar [27] investigated the radiation and viscous dissipation effects on MHD oscillatory flow in a channel filled with porous medium in the presence of chemical reaction. Sarkar et al. [30] investigated the magnetohydrodynamic peristaltic flow of nanofluids in a convectively heated vertical asymmetric channel in the presence of a transverse magnetic field and thermal radiation. Mohammed Ibrahim, Gangadhar and Bhaskar Reddy [29] investigated the radiation and mass transfer effects on MHD boundary layer flow for the Blasius and Sakiadis flows with a convective surface boundary condition.

2. Mathematical formulation

Consider steady, laminar, heat, and mass transfer by mixed convection, boundary layer stagnation-point flow of an electrically conducting and radiating, viscous dissipative, optically dense, and non-Newtonian power-law fluid obeying the Ostwald-de Waele model (see [33]) past a heated or cooled stretching vertical surface in the presence of the presence of suction/injection and heat generation/absorption with effect of the slip model and concluded that the reduced Nusselt number decreases with increase of Nt and Nb. Gangadh [28] investigated the radiation, heat generation and viscous dissipation effects on MHD boundary layer flow for the Blasius and Sakiadis flows with a convective surface boundary condition. Mohammed Ibrahim, Gangadhar and Bhaskar Reddy [29] investigated the radiation and mass transfer effects on MHD oscillatory flow in a channel filled with porous medium in the presence of chemical reaction. Sarkar et al. [30] investigated the magnetohydrodynamic peristaltic flow of nanofluids in a convectively heated vertical asymmetric channel in the presence of a transverse magnetic field and thermal radiation. Bhargava and Goyal [31] investigated the MHD non-Newtonian nanofluid flow over a permeable stretching sheet with heat generation and velocity slip. Murthy et al. [32] studied the influence of the prominent viscous dissipation and chemical reaction effects on boundary layer stagnation point flow past a stretching/shrinking sheet in a nanofluid for both assisting and opposing flows.

However, the interactions of MHD mixed convection boundary layer flow of heat and mass transfer stagnation-point flow of a non-Newtonian power-law nanofluid towards a stretching surface with thermal radiation and heat source/sink in the presence of viscous dissipation and variable suction/injection is investigated numerically. The governing boundary layer equations have been transformed to a two-point boundary value problem in similarity variables and the resultant problem is solved numerically using bvp4c MATLAB solver. The effects of various governing parameters on the fluid velocity, temperature, concentration, Skin-friction and the rate of heat and mass transfer are shown in figures and analyzed in detail.
It is assumed that the stretching velocity is given by \( u_w(x) = cx \) and the velocity distribution in frictionless potential flow in the neighborhood of the stagnation point at \( x = y = 0 \) is given by \( U(x) = ax \). We assumed that the uniform wall temperature \( T_w \) and nanoparticles volume fraction \( C_w \) are higher than those of their full stream values \( T_w, C_w \). A uniform magnetic field is applied in the \( -z \)-direction normal to the flow direction. The magnetic Reynolds number is assumed to be small so that the induced magnetic field is neglected. In addition, the Hall effect and the electric field are assumed to be negligible. The small magnetic Reynolds number assumption uncouples the Navier-Stokes equations from Maxwell’s equations. All physical properties are assumed to be constant except for the density in the buoyancy force term. By invoking all of the boundary layer, Boussinesq and Rosseland diffusion approximations, the governing equations for this investigation can be written as

Continuity equation

\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{2.1}
\]

Momentum equation

\[
u \left( \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right) = U \frac{dU}{dx} + \frac{1}{\rho} \frac{\partial \tau_{xy}}{\partial y} + g \beta (T - T_\infty) + g \beta^* (C - C_\infty) - \frac{\sigma B_0^2}{\rho} (u - U) \tag{2.2}
\]

Energy equation

\[
u \frac{\partial T}{\partial x} + \frac{\partial T}{\partial y} = \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial y^2} \left( \frac{T}{T_\infty} \right)^2 + \frac{\nu}{\rho c_p} \left( \frac{\partial u}{\partial y} \right)^2 + \frac{Q_0}{\rho c_p} \left( T - T_\infty \right) - \frac{1}{\rho c_p} \frac{\partial q_y}{\partial y} \tag{2.3}
\]

\[
u \frac{\partial C}{\partial x} + \frac{\partial C}{\partial y} = \frac{\partial^2 C}{\partial y^2} + \frac{\partial^2 C}{\partial y^2} + \frac{\partial^2 C}{\partial y^2} \left( \frac{T}{T_\infty} \right)^2 \tag{2.4}
\]

The boundary conditions are

\[
\begin{align*}
    u &= u_w(x) = cx, \quad v = -u_w(x), T = T_w, C = C_w \quad \text{at} \quad y = 0 \\
    u &\to U(x), T \to T_w, C \to C_w \quad \text{as} \quad y \to \infty
\end{align*} \tag{2.5}
\]
, \(v\), and are the and components of velocity, temperature, and nanoparticle volume fraction, respectively. \(g, \rho, \alpha, D, D, B, \beta, \beta\) are the gravitational acceleration, fluid density, thermal diffusivity, Brownian diffusion coefficient, thermophoretic diffusion coefficient, magnetic field, coefficient of thermal expansion, and coefficient of concentration of expansion, respectively. \(u(x) > 0\) is velocity of suction and \(v(x) < 0\) is velocity of injection, respectively.

The term \(Q_0 (T - T_\infty)\) is assumed to be the amount of heat generated or absorbed per unit volume \(Q_0\) as a coefficient constant, which may take on either positive or negative value. When the wall temperature exceeds the free stream temperature \(T_\infty\) the source term \(Q_0 > 0\) and heat sink when \(Q_0 < 0\). We have \(\frac{\partial T}{\partial y} > 0\) when \(\frac{a}{c} > 0\) (the ratio of free stream velocity and stretching velocity) which gives the shear stress as

\[ \tau_{xy} = K \frac{\partial (\frac{\partial u}{\partial y})}{\partial y} \]  

(2.6)

where \(K\) is the consistency coefficient and \(\eta\) is the power-law fluid. It needs to be mentioned that, for the non-Newtonian power-law model, the case of \(\eta < 1\) is associated with shear thinning fluids (pseudoplastic fluids); \(\eta = 1\) corresponds to Newtonian fluids and \(\eta > 1\) applies to the case of shear thickening (dilatant).

Using the Rosseland approximation for radiation, the radiative heat flux is simplified as

\[ q_r = -\frac{4\sigma \alpha}{3k\beta} \frac{\partial T^4}{\partial y} \]  

(2.7)

where \(\sigma\) and \(k\) are the Stefan-Boltzmann constant and the mean absorption coefficient, respectively. We assume that the temperature differences within the flow, such as the term \(T^4\), may be expressed as a linear function of temperature. Hence, expanding \(\alpha\) in a Taylor series about a free stream temperature \(T_\infty\) and neglecting higher-order terms, we get

\[ T^4 = 4T^4T - 3T^4_{\infty} \]  

(2.8)

Using (2.7) and (2.8) in the last term of (2.3), we obtain

\[ \frac{\partial q_r}{\partial y} = -\frac{16\sigma \alpha T^4}{3k\beta} \frac{\partial T^4}{\partial y^2} \]  

(2.9)

In order to reduce the governing equations into a system of ordinary differential equations, the following dimensionless parameters are introduced

\[ \psi = \left( \frac{K}{\rho} \right) x^{2n/(n+1)} f(\eta), \eta = y \left( \frac{c^2}{K/\rho} \right)^{1/(n+1)} \]  

(2.10)

It is worth mentioning that the continuity equation (2.1) is identically satisfied from our choice of the stream function with \(u = \frac{\partial \psi}{\partial y}\) and \(v = -\frac{\partial \psi}{\partial x}\).

Substituting the dimensionless parameters into (2.2)-(2.4) gives

\[ n \left( f^n \right)^{n+1} f''' + \left( \frac{2n}{n+1} \right) f f'' - f' - Mf' + MC + C^2 + \delta (\theta + N\phi) = 0 \]  

(2.11)

\[ \frac{1}{Pr} \left( 1 + \frac{4R}{3} \right) \theta'' + \left( \frac{2n}{n+1} \right) f \theta' + Nb \theta' = Nt\theta'' + Ef \theta' + Q \theta = 0 \]  

(2.12)

\[ \phi'' + \left( \frac{2n}{n+1} \right) Lef \phi' + \frac{Nt}{Nb} \theta'' = 0 \]  

(2.13)

The transformed boundary conditions can be written as
\( f(0) = \frac{2n-1}{2n} f_w, f'(0) = 1, \theta(0) = 1, \phi(0) = 1 \)
\[ f' \to C, \theta \to 0, \phi \to 0 \quad \text{as} \quad \eta \to \infty \] (2.14)

where primes denote differentiation with respect to \( \eta \rightarrow \infty \) as \( \eta \to \infty \)

\[
\begin{align*}
M = \frac{\sigma B^2}{\rho c}, & \quad \delta = \frac{g \beta (T_w - T_\infty)}{u^2 x^2 / \nu^2}, & \quad N = \frac{g \beta^* (C_w - C_\infty)}{g \beta (T_w - T_\infty)} \\
Pr = \frac{\nu}{\alpha_m} (c^2 \Re_x)^{(n-1)/(n+1)}, & \quad R = \frac{4 \sigma^* T^3}{k k^*}, & \quad Nb = \frac{\tau D_B}{\nu} (c^2 \Re_x)^{(1-n)/(n+1)} \\
Nt = \frac{\tau D_B}{T_w - T_\infty} (c^2 \Re_x)^{(1-n)/(n+1)}, & \quad Le = \frac{\nu}{D_B} (c^2 \Re_x)^{(n-1)/(n+1)}, & \quad Q = \frac{Q_0}{(\rho c)^f} \\
f_w = \left( \frac{c^{1-2n}}{K / \rho} \right)^{(n/(n+1))} \nu_w, & \quad Ec = \frac{u_w^2}{c_p (T_w - T_\infty)} (c^2 \Re_x)^{(1-n)/(n+1)} \\
\end{align*}
\]

where \( \Re_x = \frac{u_w x}{\nu} \) is the local Reynolds number based on the stretching velocity \( u_w(x) \) and \( k \) is the thermal conductivity. \( f_w > 0 \ ( < 0 ) \) is the suction (or injection), It should be noted that \( \delta > 0 \) corresponds to an assisting flow (heated plate), \( \delta < 0 \) corresponds to an opposing flow (cooled plate), and \( \delta = 0 \) yields forced convection flow.

The physical quantities of interest are the wall skin friction coefficient \( \sigma_w \) the local Nusselt number \( \Nu \) and the local Sherwood number \( \Sh \), which are defined as

\[
\begin{align*}
C_{f_k} &= 2 \left[ f''(0) \right] \left( \frac{c x}{2-n} \frac{K / \rho}{x} \right)^{-1/(1+n)} \\
\Nu_x &= -K \left( \frac{u_w}{K / \rho} \right)^{1/(n+1)} \left( 1 + \frac{4R}{3} \right) \theta(0) \\
\Sh_x &= -D \left( \frac{u_w}{K / \rho} \right) \phi'(0) \\
\end{align*}
\]

where \( \Re_x = \frac{u_w x}{\nu_f} \) is the local Reynolds number.

3 Solution of the problem

The set of equations (2.11) to (2.13) were reduced to a system of first-order differential equations and solved using a MATLAB boundary value problem solver called bvp4c. This program solves boundary value problems for ordinary differential equations of the form

\[ y' = f(x, y, p), a \leq x \leq b, \quad \text{by implementing a collocation method subject to general nonlinear, two-point boundary conditions} \quad g(y(a), y(b), p). \]

Here \( p \) is a vector of unknown parameters. Boundary value problems (BVPs) arise in diverse forms. Just about any BVP can be reformulated for solution with bvp4c. The first step is to write the ODEs as a system of first-order ordinary differential equations. The details of the solution method are presented in Shampine and Kierzenka[34].

4 Results and discussions

The numerical results are compared in Tables 1 for local Sherwood number. Figs. 1(a)–1(c) illustrate the variation of velocity, temperature, and nanoparticles volume fraction profiles, respectively, for different values of power-law index. The velocity, temperature, and nanoparticles volume fraction profiles decrease with the increase of power-law index from 0.6 to 1.4. The effect of the increased values of \( \delta \) is to reduce the boundary layer thickness. It can be observed from Fig. 1(b) that the effect of power-law index
increases from 0.6 to 1.4; the temperature profiles decrease with an increasing viscosity of nanofluid, and thermal diffusion is depressed in the resumewhich cools the boundary layer and decreases the boundary layer thickness. It can also be seen from Fig. 1(c) that the increase of power-law index from 0.6 to 1.4 decreases than nanoparticle volume fraction which decreases diffusion of nanoparticle volume fraction (concentration) boundary layer thickness.

Figs. 2-4 present the changes in the velocity, temperature and concentration profiles with the effect of magnetic parameter for shearthinning ( < 1), Newtonian ( = 1), and shear-thickening ( > 1) fluids, respectively. The velocity profiles decrease with the raising of magnetic parameter. This is due to magnetic field opposing the transport phenomena, since the variation of magnetic parameter causes the variation of Lorentz forces. The Lorentz force is a drag like force that produces more resistance to transport phenomena and that causes reduction in the fluid velocity. The effect of magnetic field is more in shear-thinning fluids than shearthickening fluids. The effect of magnetic fields increases the temperature and concentration profiles (Figs. 3&4).

Fig. 5-7 presents the velocity, temperature, and concentration profiles for various values of ratio of velocity parameter C. It can be observed that an increase in C causes increase in velocity profiles and significant decrease on the temperature and concentration profiles. Figs 8-10 show the effect of dimensionless mixed convection parameter δ on velocity, temperature, and concentration profiles, respectively. The velocity profiles are increasing with increasing values of δ whereas temperature and concentration profiles are decreasing with increasing values of δ. The presence of the thermal buoyancy effect is represented by finite values of the mixed parameter has the tendency to induce more flow along the surface at the expense of small reductions in the temperature and concentration. Distinctive peaks in the velocity profiles which are characteristics of free convection flows are also observed as increases.

Fig. 11-13 show the effect of thermal buoyancy ratio on velocity, temperature, and concentration profiles for shear-thinning ( < 1), Newtonian ( = 1), and shear-thickening ( > 1) fluids, respectively. It is noticed that the increase of values has a tendency to increase the buoyancy effects changing more induced flow along the stretching sheet in the vertical direction reflected by the increase in the fluid velocity and decrease in the fluid temperature and concentration. This enhancement in the fluid velocity has more in shear-thinning fluid ( < 1) than shear-thickening fluid ( > 1). This reduction in the fluid temperature and concentration has more in shear-thinning fluid ( < 1) than shear-thickening fluid ( > 1). Figs. 14-16 present the velocity, temperature, and concentration profiles for various values of ratio of suction/injection parameter fw. It can be observed that an increase in fw causes decrease on the velocity, temperature, and concentration profiles.

The effect of thermophoresis parameter is to increase velocity, temperature, and concentration profiles for both Newtonian and non-Newtonian fluids. It is noticed that the increase of radiation parameter values has a tendency to increase velocity, temperature, and concentration profiles for both Newtonian and non-Newtonian fluids. It is noticed that the increase of radiation parameter values has a tendency to increase velocity, temperature, and concentration profiles. The variations in heat source/sink parameter on velocity, temperature and concentration profiles are given in Fig. 23-25; from the figure it can be seen that the velocity as well as temperature profiles increase with the increase of heat source/sink parameter but concentration increases near the plate and decreases for away the plate. A gradually increasing heat source/sink parameter increases the thermal boundary layer thickness which physically reveals the fact that an increase in the heat source/sink parameter means an increase in the heat generated inside the boundary layer which leads to higher temperature field. It is noted that the temperature profiles decrease for increasing strength of heat sink and due to increase of heat source strength the temperature increases. So the thickness of the thermal boundary layer reduces for increase with heat source parameter. These results are very much significant for the flow where heat transfer is given prime importance. Figs. 26-27 are drawn for the velocity and temperature profiles for different values of Prandtl number Pr for the cases shear-thinning ( < 1), Newtonian ( = 1), and shear-thickening ( > 1) fluids. The effect of Prandtl number Pr is to reduce the velocity and temperature profiles for both Newtonian and non-Newtonian fluids. Physically, fluids with smaller Prandtl number Pr have larger thermal diffusivity.

Fig. 28 shows the effect of radiation parameter on the velocity profiles for both Newtonian and non-Newtonian fluids. It is noticed from the figure that the velocity of the fluid increases with the increase of radiation parameter values. It can be shown from Fig. 29 that temperature of the fluid increases with the
increase of radiation parameter. As expected, an increase of the radiation parameter has the tendency to increase the effect of conduction as well as increasing the temperature at each point away from the surface. Hence, higher values of radiation parameter imply a higher surface heat flux. The variations in Eckert number $ Ec $ and temperature profiles are given in Fig. 30-31; from the figure, it can be seen that the velocity decreases but temperature increases with the increase of Eckert number $ Ec $ values.

Fig. 32 shows the effect of $ Nt $, $ Nb $ and $ fw $ on local Nusselt number for shear-thinning ($ < 1 $), Newtonian ($ = 1 $), and shear-thickening ($ > 1 $) fluids, respectively. It is noticed that the increase of $ t $ or $ Nb $ values has a tendency to decrease the Nusselt number whereas increase the Nusselt number with an increase the values of $ fw $.

5 Conclusions

In this paper two-dimensional MHD mixed convection boundary layer flow of heat and mass transfer stagnation-point flow of a non-Newtonian power-law nanofluid towards a stretching surface with thermal radiation and heat source/sink in the presence of viscous dissipation and variable suction/injection is investigated numerically. Using similarity transformations, the governing equations are transformed to self-similar ordinary differential equations which are then solved using Bvp4c MATLAB solver. From the study, the following remarks can be summarized.

1. Fluid velocity, temperature and concentration increases with an increasing the values of thermophoresis parameter.
2. Fluid velocity, temperature and concentration decreases with an increasing the values of suction/injection parameter.
3. Fluid velocity decreases and fluid temperature increases with the influence of viscous dissipation.
4. Fluid velocity and temperature of the fluid increases with a rising the values of Brownian motion parameter whereas concentration decreases with the influence of Brownian motion parameter.
5. Local Nusselt number decreases with an increase Brownian motion parameter and thermophoresis parameter but in the presence of suction/injection the local Nusselt number increases.

Table 1: Comparison of $ -\theta'(0) $ when $ Pr=Le=10 $, $ n=1 $, $ M = fw = Ec = \delta = Q = 0 $.

<table>
<thead>
<tr>
<th>$ Nt $</th>
<th>$ Nb $</th>
<th>$ \phi''(0) $</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.1</td>
<td>2.12938</td>
</tr>
<tr>
<td>0.2</td>
<td>0.1</td>
<td>2.27401</td>
</tr>
<tr>
<td>0.3</td>
<td>0.1</td>
<td>2.52868</td>
</tr>
<tr>
<td>0.4</td>
<td>0.1</td>
<td>2.79519</td>
</tr>
<tr>
<td>0.5</td>
<td>0.1</td>
<td>3.03510</td>
</tr>
<tr>
<td>0.1</td>
<td>0.2</td>
<td>3.38182</td>
</tr>
<tr>
<td>0.1</td>
<td>0.3</td>
<td>4.09995</td>
</tr>
<tr>
<td>0.1</td>
<td>0.4</td>
<td>4.39961</td>
</tr>
<tr>
<td>0.1</td>
<td>0.5</td>
<td>4.38256</td>
</tr>
</tbody>
</table>
Fig. 1: Effect of power-law index on velocity, temperature, and concentration profiles.

Fig. 2: Effect of M on velocity profiles for pseudoplastic, Newtonian, and dilatant fluids.
3(c) Fig. 3: Effect of $M$ on temperature profiles for pseudoplastic, Newtonian, and dilatant fluids.

4(a) Fig. 4: Effect of $M$ on concentration profiles for pseudoplastic, Newtonian, and dilatant fluids.

4(b) Fig. 4: Effect of $M$ on concentration profiles for pseudoplastic, Newtonian, and dilatant fluids.

4(c) Fig. 4: Effect of $M$ on concentration profiles for pseudoplastic, Newtonian, and dilatant fluids.

5(a) Fig. 5: Effect of $C$ on velocity profiles for pseudoplastic Newtonian, and dilatant fluids.

5(b) Fig. 5: Effect of $C$ on velocity profiles for pseudoplastic Newtonian, and dilatant fluids.

5(c) Fig. 5: Effect of $C$ on velocity profiles for pseudoplastic Newtonian, and dilatant fluids.
Fig. 6: Effect of $C$ on temperature profiles for pseudoplastic, Newtonian, and dilatant fluids.

Fig. 7: Effect of $C$ on concentration profiles for pseudoplastic, Newtonian, and dilatant fluids.

Fig. 8: Effect of $\delta$ on velocity profiles for pseudoplastic, Newtonian, and dilatant fluids.
Fig. 9: Effect of $\delta$ on temperature profiles for pseudoplastic, Newtonian, and dilatant fluids.

Fig. 10: Effect of $\delta$ on concentration profiles for pseudoplastic, Newtonian, and dilatant fluids.

Fig. 11: Effect of $\delta$ on velocity profiles for pseudoplastic, Newtonian, and dilatant fluids.

Fig. 12: Effect of $\delta$ on temperature profiles for pseudoplastic, Newtonian, and dilatant fluids.
Fig. 13: Effect of on concentration profiles for pseudoplastic, Newtonian, and dilatant fluids.

Fig. 14: Effect of on velocity profiles for pseudoplastic, Newtonian, and dilatant fluids.

Fig. 15: Effect of on temperature profiles for pseudoplastic, Newtonian, and dilatant fluids.
Fig. 16: Effect of $f_{w}$ on concentration profiles for pseudoplastic, Newtonian, and dilatant fluids.

Fig. 17: Effect of $t$ on velocity profiles for pseudoplastic, Newtonian, and dilatant fluids.

Fig. 18: Effect of $t$ on temperature profiles for pseudoplastic, Newtonian, and dilatant fluids.
Fig. 19: Effect of $t$ on concentration profiles for pseudoplastic, Newtonian, and dilatant fluids.

Fig. 20: Effect of $\delta$ on velocity profiles for pseudoplastic, Newtonian, and dilatant fluids.

Fig. 21: Effect of $\delta$ on temperature profiles for pseudoplastic, Newtonian, and dilatant fluids.

Fig. 22: Effect of $\delta$ on concentration profiles for pseudoplastic, Newtonian, and dilatant fluids.
Fig. 23: Effect of \( Q \) on velocity profiles for pseudoplastic, Newtonian, and dilatant fluids.

\[ n = 0.6, \quad n = 1, \quad n = 1.4 \]

\[ Q = -0.4, 0, 0.4, 0.8 \]

\[ \delta = N = f_w = 1, \quad R = E_c = C = N_b = N_t = 0.1, \quad Pr = Le = M = 2 \]

Fig. 24: Effect of \( Q \) on temperature profiles for pseudoplastic, Newtonian, and dilatant fluids.

\[ n = 0.6, \quad n = 1, \quad n = 1.4 \]

\[ Q = -0.4, 0, 0.4, 0.8 \]

\[ \delta = N = f_w = 1, \quad R = E_c = N_b = C = N_t = 0.1, \quad Pr = Le = M = 2 \]

Fig. 25: Effect of \( Q \) on concentration profiles for pseudoplastic, Newtonian, and dilatant fluids.

\[ n = 0.6, \quad n = 1, \quad n = 1.4 \]

\[ Q = -0.4, 0, 0.4, 0.8 \]

\[ \delta = N = f_w = 1, \quad R = E_c = N_b = C = N_t = 0.1, \quad Pr = Le = M = 2 \]
Fig. 26: Effect of $Pr$ on velocity profiles for pseudoplastic, Newtonian, and dilatant fluids.

Fig. 27: Effect of $R$ on velocity profiles for pseudoplastic, Newtonian, and dilatant fluids.

Fig. 28: Effect of $R$ on temperature profiles for pseudoplastic, Newtonian, and dilatant fluids.

Fig. 29: Effect of $R$ on temperature profiles for pseudoplastic, Newtonian, and dilatant fluids.
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Fig.29: Effect of $R$ on temperature profiles for pseudoplastic, Newtonian, and dilatant fluids.

Fig.30: Effect of $E_c$ on velocity profiles for pseudoplastic, Newtonian, and dilatant fluids.

Fig.31: Effect of $E_c$ on temperature profiles for pseudoplastic, Newtonian, and dilatant fluids.

Fig.32: Effect of $N_t$, $N_b$ and $f_w$ on Nusselt number for pseudoplastic, Newtonian, and dilatant fluids.

References


