CHAPTER 7

MHD effects on non-Newtonian Micro Polar fluid with uniform suction/blowing and Heat Generation in the presence of Chemical Reaction and Thermophoresis

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Name of the Sub-Title</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1</td>
<td>Introduction</td>
<td>130-132</td>
</tr>
<tr>
<td>7.2</td>
<td>Mathematical formulation</td>
<td>132-135</td>
</tr>
<tr>
<td>7.3</td>
<td>Numerical solution</td>
<td>135-137</td>
</tr>
<tr>
<td>7.4</td>
<td>Results and discussion</td>
<td>137-140</td>
</tr>
<tr>
<td>7.5</td>
<td>Conclusion</td>
<td>140-141</td>
</tr>
<tr>
<td>7.6</td>
<td>Graphs and Tables</td>
<td>142-149</td>
</tr>
</tbody>
</table>
CHAPTER 7

7.1 Introduction

The theory of micro polar fluids due to importance during the last few decades attracted attention. Eringen [35] is investigated the theory of microstructure and the intrinsic motion of the fluids effects arising locally and it should be considered. Later, Eringen [36] extended the same theory for thermo-micro polar fluids and obtained the constitutive laws for fluids with microstructure. Airman et al. [8], Gorla [42], Rees and Pop [88] extended the study on micro polar fluids and presented excellent review on these applications. Singh [99] has given numerical solution to a micro polar fluid flow past an infinite vertical plate.

The numerous industrial applications consisting of such processes like manufacturing of ceramics/glassware, the polymer production [24]. Das studied the fluid flow past an impulsively started infinite vertical plate under the effects of a first order chemical reaction. Muthucumarswamy [70,71] studied first order homogeneous chemical reaction.

Thermophoresis is a mechanism of migration of small particles in direction of decreasing thermal gradient by Hinds.W.C [46]. It is an effective method for particle collection by TSai et al.[109]. The velocity acquired by the particle is called thermophoretic velocity and the force experienced by the suspended particle is called thermophoretic force by Bakier et al. [9]. Balaram and Sastry [10] discussed a fully
developed convection flow in a micro polar fluid flow. Agarwal and Dhanapal [2] obtained a numerical solution to study the fully developed free convection micro polar fluid flow between two parallel with constant suction (or injection). The effects of micro rotation and frequency parameters on an unsteady flow of micro polar fluid between two parallel porous plates with a periodic suction is investigated by Srinivasacharya et al. [104].

The rate of heat flow depends on the parameter of micro rotation. El-Hakiem et al. [33][43] analyzed the effect of viscous and Joule heating on the flow of an electrically conducting and micro polar fluid past a plate whose temperature varies linearly with the distance from the leading edge in the presence of a uniform transverse magnetic field. Helmy et al. [45] studied the unsteady flow MHD of a conducting micro polar fluid flow of an infinite plate through a porous medium that is set in motion in its own plane by an impulse. Bhargava et al. [15] obtained a numerical solution of convection MHD, micro polar fluid flow between two parallel porous vertical plates.

Recently. R. A. Mohamed1 et al. and Ziabakhsh et al. studied [68,115] Heat and mass transfer analysis on the flow of micro polar fluid with uniform suction/blowing, heat generation, thermophoresis and chemical reaction.

The aim of present investigation on the effects of MHD non-Newtonian micro polar fluid flow with uniform suction/blowing heat generation, thermophoresis, chemical reaction and radiation. We solved the non-linear boundary value problem arising from the non
dimensionalization and local non similarity method using an implicit finite difference scheme along with Gauss-Seidal method. The C-programming code is used to solve the system equations.

7.2 Mathematical formulation

Consider steady, two-dimensional stagnation point flow of an incompressible non-Newtonian micro-polar fluid impinging perpendicular on permeable wall and flowing away parallel x-axis. A uniform magnetic field $\beta_0$ is applied normal to the walls. In the energy equation considering heat generation or absorption, thermal radiation and neglecting viscous dissipation, with the inclusion of thermophoresis and chemical reaction in the equation of mass. The simplified, 2-D steady, laminar and incompressible micro-polar fluid the governing equations are:

\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (7.2.1)
\]

\[
\rho \left( u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} \right) = (\mu + k) \left( \frac{\partial^2 u}{\partial y^2} \right) + k \frac{\partial N}{\partial y} - \frac{\sigma \beta^2}{\rho} u \quad (7.2.2)
\]

\[
\rho \left( u \frac{\partial N}{\partial x} + v \frac{\partial N}{\partial y} \right) = \tau \frac{\partial N}{\partial y} - \frac{k_f}{j} \left( 2N + \frac{\partial u}{\partial y} \right) \quad (7.2.3)
\]

\[
\rho c_p \left( u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} \right) = k \left( \frac{\partial T}{\partial y^2} \right) + Q(T - T_w) - \frac{\partial q_r}{\partial y} \quad (7.2.4)
\]

\[
u \frac{\partial c}{\partial x} + v \frac{\partial c}{\partial y} = D \frac{\partial c}{\partial y^2} - \frac{\partial}{\partial y} (\nu c) - R c \quad (7.2.5)
\]

In the above equations

$N$ is the angular velocity or micro rotation whose direction of rotation is in xy plane, $\mu$ is the viscosity of the fluid flow, $\rho$ is the density of the fluid, $c_p$ is the specific heat capacity at constant pressure, $k_f$ is the thermal conductivity, $R'$ is the rate of chemical reaction, $D$ is
mass diffusivity, $Q$ is the heat generation/absorption coefficient. $j$ is the micro inertia per unit mass, $\gamma$ is the spin gradient viscosity and $k$ is the vortex viscosity which are assumed to be constant.

The boundary conditions of the problem are:

$$u(x,0) = 0; \quad v(x,0) = -v_0, \quad N(x,0) = -n \frac{\partial u}{\partial x}$$

$$\gamma \rightarrow \infty: \quad u(x,y) - U(x) = ax, \quad v(x,y) = 0, \quad N(x,y) = 0 \quad (7.2.6)$$

$$y = 0: \quad T = T_w \quad c = c_w$$

$$y = \infty: \quad T = T_{\infty} \quad c = c_{\infty}$$

Here $n$ is a constant and $0 \leq n \leq 1$. In the case $n = \frac{1}{2}$ denote for anti-symmetric part of the stress tensor and indicate weak concentration of micro elements.

Using the transform

$$\eta = \sqrt{\frac{a}{v}} y, \quad u = a x f'(\eta), \quad v = -\sqrt{a v} f(\eta)$$

$$N = a x \sqrt{\frac{a}{v}} g(\eta), \quad g(\eta) = -\frac{1}{2} f'(\eta) \quad \theta = \frac{T-T_{\infty}}{T_w-T_{\infty}}$$

$$\phi = \frac{c-c_{\infty}}{c_w-c_{\infty}} \quad (7.2.7)$$

With the usage of (7.2.7), the equations (7.2.2) and (7.2.3) are reduced. Here we have two equations $f(\eta)$ and $g(\eta)$ where

$$g(\eta) = \frac{-1}{2} f^m(\eta) \quad [115]$$

So Eqns.(7.2.2) and (7.2.3) reduce to the single equation (7.2.8a)

$$\left(1 + \frac{k}{2}\right) f^m(\eta) + f(\eta)f'(\eta) - f'(\eta)^2 - Ha^2 f' + 1 = 0 \quad (7.2.8a)$$

$$\left(1 + \frac{4}{3} R\right) \theta'(\eta) + Prf(\eta)\theta(\eta) + PrB\theta(\eta) = 0 \quad (7.2.8b)$$

$$\phi''(\eta) + Sc \left(f - \tau \theta' \right) \phi' - Sc \tau \phi \theta'' - \delta Sc \phi = 0 \quad (7.2.8c)$$
The boundary conditions reduces to
\[ f(0) = A, \quad f'(0) = 0, \quad f'(\infty) = 1 \]
\[ \theta(0) = 1, \quad \theta(\infty) = 0 \]
\[ (0) = 1, \quad \phi(\infty) = 0 \]  \hspace{1cm} (7.2.8d)

In the above equations
- \( K = \frac{k}{\mu} \) (\( > 0 \)) material parameter
- \( A = \frac{v_0}{\sqrt{uv}} \) suction parameter
- primes differentiation with respect to \( \eta \)
- \( Pr = \frac{\mu c_p}{k} \) Prandtl number
- \( B = \frac{Q}{\alpha p c_p} \) heat Generation/absorption parameter
- \( Ha = \frac{\sigma \beta\partial}{\rho v} \) magnetic parameter
- \( Sc = \frac{\mu}{\rho D} \) Schmidt number
- \( \delta = \frac{x R^*}{u} \) chemical reaction parameter
- \( \tau = \frac{-k f}{T_r} (T_w - T_x) \) thermophoretic parameter
- \( R = \frac{4 \alpha^* T^*_w}{k^* k} \) radiation parameter
- \( T_w \) wall skin friction

The skin friction coefficient is defined as characteristic velocity,
\[ u(x) = ax \text{ and } C_f \text{ as} \]
\[ C_f = \frac{T_w}{\rho U^2} \]  \hspace{1cm} (7.2.10)

By using this definition we have
\[ C_f Re_x^{1/2} = (1 + \frac{k}{\bar{z}}) f''(0) \]  \hspace{1cm} (7.2.11)

Where \( Re_x^{1/2} = \frac{x U}{v} \) is the local Reynolds number.
Using the application of Fourier’s law the heat transfer from the surface to the fluid is computed.

\[ q = \left( \frac{16 \sigma^* T_v^3}{3 k^*} \right) \left. \frac{\partial T}{\partial y} \right|_{y=0} \quad (7.2.12) \]

where \( \sigma^* \) is the Stefan-Boltzmann constant and \( k^* \) is the mean absorption coefficient.

In Equation (7.2.5)) the thermophoretic velocity \( v_T \) was defined by Talbot et al [107]

\[ V_T = -k v \frac{\nabla T}{T} = -k v \frac{\partial T}{\partial y} \]

where \( k \) is the thermophoretic coefficient, which was defined by Batchelor [12]

Introducing the similarity transformed variables, the expression for \( q \) becomes and the heat transfer coefficient, the Nusselt number \( Nu \) can be expressed as

\[ Nu = \frac{q}{k(T_w-T_0)\sqrt{\frac{\pi}{v}}} \quad (7.2.13) \]

Then we have \( Nu = -\theta'(0) \)

The local mass flux is defined by

\[ j_w = -D \left( \frac{\partial c}{\partial y} \right)_{y=0} \quad (7.2.14) \]

The local Sherwood number is given as

\[ sh_x = \frac{j_w}{D(c_w-c_x)\sqrt{\frac{\pi}{v}}} \quad (7.2.15) \]

### 7.3 Numerical solution

Applying the Quasi-linearization technique [14] to the non-linear equation (7.2.8a) we obtain as

\[ (1+K/2) f'' + (F) f' + (-2F'Ha^2) f' + F''f = FF'' - FF' - 1 \quad (7.3.1) \]
Where assumed $F$ is the value of $f$ at $n^{th}$ iteration and $f$ is at $(n+1)^{th}$ iteration. The convergence criterion is fixed as $|F - f| < 10^{-5}$.

Applying an implicit finite difference scheme for the equation (7.3.1), (7.2.8b) and (7.2.8c), we obtain

$$a[i] f[i+2] + b[i] f[i+1] + c[i] f[i] + d[i] f[i-1] = e[i]$$  \hspace{3em} (7.3.2)\\
$$a_1[i] \theta[i+1] + b_1[i] \theta[i] + c_1[i] \theta[i-1] = 0$$  \hspace{3em} (7.3.3)\\
$$a_2[i] \phi[i+1] + b_2 \phi[i] + c_2 \phi[i-1] = 0$$  \hspace{3em} (7.3.4)

where

$$a[i] = A[i], \quad b[i] = -3A[i] + h B[i] + 0.5 h^2 C[i]$$

$$c[i] = 3A[i] - 2 h B[i] + h^3 D[i],$$

$$d[i] = -A[i] + h B[i] - 0.5 h^2 C[i]$$

$$e[i] = h^3 E[i]$$

$$a_1 = A_1[i] + 0.5 h B_1[i],$$

$$b_1 = -2A_1[i] + h^2 C_1[i]$$

$$c_1 = A_1[i] - 0.5 h B_1[i],$$

$$a_2 = A_2[i] + 0.5 h B_2[i]$$

$$b_2 = -2A_2[i] + h^2 C_2[i],$$

$$c_2 = A_2[i] - 0.5 h B_2[i]$$

$$A[i] = 1 + \frac{k}{2}, \quad B[i] = F,$$

$$C[i] = -2F'' - \alpha^2,$$

$$D[i] = F''' E[i] = FF'' - F'F' - 1,$$

$$A_1[i] = 1 + 4/3 R,$$

$$B_1[i] = Pr f[i]$$

$$C_1[i] = Pr B$$
A uniform grid was adopted to concentrate towards the wall. The calculations are repeated until some convergent criterion is satisfied and the calculations are stopped $|F_f| \leq 10^{-5}$. In the present study, the boundary conditions for $\eta$ at $\infty$ are replaced by a sufficient large value of $\eta$ where the velocity approaches 1, at temperature and concentration approaches zero. In order to see the effects of step size $h$ run the code for our model with two different step sizes as $h = 0.001$ and 0.05 and in each case we found very good agreement between them on different profiles. Hence the finite difference method is convergent.

### 7.4 Results and Discussion

The calculations are carried out numerically for different physical parameters, such as material parameter $K$, suction parameter $A$, heat generation/absorption parameter $B$, Prandtl number $Pr$, radiation parameter $R$, thermophoretic parameter $\tau$, chemical reaction parameter $\delta$, Schmidt number $Sc$ and magnetic number $Ha$. The set of results are reported in graphs from figures 7.6.1 to 7.6.7. These results are obtained to show that the flow field is influenced by $A, K, B, Pr, Sc, R, \tau, \delta$, $Ha$.

Figures 7.6.1(a)–(c) represents the dimensionless profiles such as velocity, temperature and concentration for the values of $A$ respectively. From figures it is noticed that $f'(\eta)$ enhances with the increase of suction parameter $A$. The temperature and concentration profiles are decreased with increase of suction parameter $A$. 
The effect of material parameter $K$ on velocity, temperature and concentration are displayed in figs. 7.6.2(a)-(c). It is seen that the velocity profile $f'$ decrease with increase of material parameter $K$. The temperature and concentration profiles decrease with the increase of material parameter $K$.

The effect of magnetic parameter $H_a$ are shown in figs. 7.6.(3a)-(c) for velocity, temperature and concentration profiles respectively. The presence of a magnetic field normal to the flow in an electrically conducting fluid introduces a Lorentz force which acts against the flow. This resistive force tends to slow down the flow and hence the fluid velocity decreases with the increases of the magnetic field parameter. The profiles temperature $\theta$ and concentration increase, magnetic parameter $H_a$ increases.

Figures 7.6.4a and 7.6.4b show the effect of radiation parameter $R$ on temperature and concentration profiles respectively. It is observed that the temperature distribution increase with the increase value of radiation parameter while the concentration profile decrease with the increase of radiation parameter $R$.

Effect of dimensionless parameter $Pr$ distribution on temperature $\theta$ are placed in fig. 7.6.5a. The temperature profile decreases, Prandtl number $Pr$ value increases is seen. From fig. 7.6.5b the influence of $Pr$ is to decrease concentration profile is seen.

Heat source/sink parameter $B$ effects on temperature exhibited in fig.7.6.6a. The dimensionless temperature $\theta$ decreases for increasing strength of the heat sink and due to increase of heat
source strength the temperature increases. Thus, the thickness of the boundary layer reduces for increase of heat sink parameter, whereas it increases with heat source parameter. This resultant is very much significant for the fluid flow where heat transfer is given prime importance. From fig. 7.6.6b concentration profile φ decrease as increase of parameter B is seen.

From the figure 7.6.7a it is observed that the influence of thermophoretic parameter τ is to reduce the concentration profile. Figure 7.6.7b illustrate the variation of concentration profile. The effect of increase of chemical reaction parameter δ is to decrease concentration profile is noticed from the figure. Figure 7.6.7c shows the effect of Schmidt number Sc on concentration profile. From this figure it displays that decrease the concentration profile with the increasing of Sc.

Table (7.6.1) shows the value of skin friction coefficient $f''(0)$ and the rate of heat transfer $-\theta'(0)$ for different values of K and A for fixed values of $B$ and $Pr$. It is observed from the table the skin friction coefficient $f''(0)$ decrease with the increase of $K$ whereas the value of $f''(0)$ increase with the increase of $A$. It can also be observed that the heat transfer coefficient $-\theta'(0)$ decrease with the increase of $K$ value. The heat transfer coefficient $-\theta'(0)$ increase with the increase of $A$ value from -2 to 1.

Table (7.6.2) shows that heat transfer coefficient $-\theta'(0)$ for different values of prandtl number $Pr$ and heat generation/absorption $B$. It is observed from the table heat transfer coefficient $-\theta'(0)$ value
increase with the increase of $Pr$ value whereas it decreases with the increase of $B$ value from -0.1 to 0.1.

Table 7.6.3 shows that comparison between present solution and previously published results has been included R.A. Mohamed et al. [68] and Ziabakhsh et al. [115] for the skin friction coefficient $f''(0)$ and heat transfer coefficient $\theta'(0)$. The results are in good agreement.

7.5 Conclusions

The problem of steady, laminar, two dimensional stagnation point flow of an incompressible flow non-Newtonian micro polar fluid with uniform suction/blowing, heat generation, radiation, thermophoresis and chemical reaction under the influence of magnetic field. The effect of the various dimensionless parameters are investigated.

1. The velocity profile is decreased with the increase of material parameter $K$ and magnetic parameter $Ha$ whereas reverse phenomena is observed in the case of suction parameter $\Lambda$. There is no significant difference in Prandtl number $Pr$, thermophoretic parameter $\tau$, chemical reaction parameter $\delta$, heat generation/absorption parameter $B$ and radiation parameter $R$ on velocity profile.

2. The temperature profile increases with the increase of magnetic parameter $Ha$, heat generation/absorption $B$ and radiation parameter $R$ while with the increase of suction parameter $\Lambda$, material parameter $K$ and Prandtl number $Pr$ the temperature profile decreases.
3. The concentration profile is increased with the increase of magnetic parameter $Ha$ whereas the reverse phenomena is seen in material parameter $K$, suction parameter $A$, Prandtl number $Pr$, thermophoretic parameter $\tau$, chemical reaction parameter $\delta$, heat generation/absorption parameter $B$, radiation parameter $R$ and Schmidt number $Sc$. 
Fig. 7.6.1(a) Effects of Suction parameter $A$ on velocity profile
$B=0.1, K=1.0, Pr=0.72, Sc=0.66, R=2.0, \delta=0.4, \tau=1.0$ and $Ha=0$

Fig. 7.6.1(b) Effects of Suction parameter $A$ on temperature profile
$B=1, K=1.0, Pr=0.72, Sc=0.66, R=2.0, \delta=0.4, \tau=1.0$ and $Ha=0.5$

Fig. 7.6.1(c) Effects of Suction parameter $A$ on concentration profile
$Sc = 0.66, K=1.0, Pr=0.72, \delta=0.4, B = 0.1, \tau=1.0, R = 2$ and $Ha=0.5$
Fig. 7.6.2(a) Effects of material parameter $K$ on velocity profile
$B=0.1$, $A=0$, $Pr=0.72$, $Sc=0.66$, $R=2.0$, $\delta=0.4$, $\tau=1.0$ and $Ha = 0$

Fig. 7.6.2(b) Effects of material parameter $K$ on temperature profile
$B=0.1$, $A=0$, $Pr=0.72$, $Sc=0.66$, $R=2.0$, $\delta=0.4$, $\tau=1.0$ and $Ha = 0$

Fig. 7.6.2(c) Effects of material parameter $K$ on concentration profile
$B=0.1$, $A=0$, $Pr=0.72$, $Sc=0.66$, $R=2.0$, $\delta=0.4$, $\tau=1.0$ and $Ha = 0$
Fig. 7.6.3(a) Effects of magnetic parameter $Ha$ on velocity profile
$B=0.1$, $K=1.0$, $Pr=0.72$, $Sc=0.66$, $R=2.0$, $\delta=0.4$, $\tau=1.0$ and $A=0$

Fig. 7.6.3(b) Effects of Magnetic parameter $Ha$ on temperature profile
$A=0$, $K=1.0$, $Pr=0.72$, $Sc=0.66$, $B=0.1$, $\delta=0.4$, $\tau=1.0$ and $R=2$

Fig. 7.6.3(c) Effects of Magnetic parameter $Ha$ on concentration profile
$Sc=0.66$, $K=1.0$, $Pr=0.72$, $\delta=0.4$, $B=0.1$, $\tau=1.0$, $R=2$ and $A=0$
Fig. 7.6.4(a) Effects of Radiation parameter $R$ on temperature profile
$A=0$, $K=1.0$, $Pr=0.72$, $Sc=0.66$, $B=0.1$, $\delta=0.4$, $\tau=1.0$ and $Ha=0.5$

Fig. 7.6.4(b) Effects of Radiation parameter $R$ on concentration profile
$A=0$, $K=1.0$, $Pr=0.72$, $Sc=0.66$, $B=1.0$, $\delta=0.4$, $\tau=1.0$ and $Ha=0.5$
**Fig. 7.6.5(a)** Effects of Prandtl number $Pr$ on temperature profile

$A=0$, $K=1.0$, $Ha=0.5$, $Sc=0.66$, $B=0.1$, $δ=0.4$, $τ=1.0$ and $R = 2$

**Fig. 7.6.5(b)** Effects of Prandtl number $Pr$ on concentration profile

$A=0$, $K=1.0$, $Ha=0.5$, $Sc=0.66$, $B=0.1$, $δ=0.4$, $τ=1.0$ and $R = 2$
**Fig. 7.6.6a** Effects of heat generation/absorption parameter $B$ on temperature profile $A=0$, $K=1.0$, $Pr=0.72$, $Sc=0.66$, $R=2.0$, $\delta=0.4$, $\tau=1.0$ and $Ha=0.5$

**Fig. 7.6.6(b)** Effects of heat generation/absorption parameter $B$ on concentration profile $A=0$, $K=1.0$, $Pr=0.72$, $Sc=0.66$, $R=2.0$, $\delta=0.4$, $\tau=1.0$ and $Ha=0.5$
**Fig. 7.6.7** Effects of thermophoretic parameter \( \tau \) on concentration profile

\( A=0, \ K=1.0, \ Pr=0.72, \ Sc=0.66, \ B=0.1, \ \delta=0.4, \ R=2 \) and \( Ha=0.5 \)

**Fig. 7.6.8a** Effects of chemical reaction parameter \( \delta \) on concentration profile

\( A=0, \ K=1.0, \ Pr=0.72, \ Sc=0.66, \ B=0.1, \ \tau=1.0, \ R=2 \) and \( Ha=0.5 \)

**Fig. 7.6.8b** Effects of Schmidt number \( Sc \) on concentration profile

\( A=0, \ K=1.0, \ Pr=0.72, \ \delta=0.4, \ B=0.1, \ \tau=1.0, \ R=2 \) and \( Ha=0.5 \)
Table 7.6.1 Results of $f''(0)$ and $-\theta'(0)$ for different values of $K$ and $A$ when $B = 0.1$ and $Pr = 0.7$

<table>
<thead>
<tr>
<th>$K$</th>
<th>$A$</th>
<th>$f''(0)$</th>
<th>$-\theta'(0)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>1.419836</td>
<td>0.403682</td>
</tr>
<tr>
<td>0.5</td>
<td>1</td>
<td>1.201999</td>
<td>0.398784</td>
</tr>
<tr>
<td>1.0</td>
<td>1</td>
<td>1.055735</td>
<td>0.39472</td>
</tr>
<tr>
<td>1.5</td>
<td>1</td>
<td>0.9498</td>
<td>0.391236</td>
</tr>
<tr>
<td>2.0</td>
<td>1</td>
<td>0.86894</td>
<td>0.388179</td>
</tr>
<tr>
<td>1</td>
<td>-2</td>
<td>0.378311</td>
<td>0.030677</td>
</tr>
<tr>
<td>1</td>
<td>-1</td>
<td>0.519675</td>
<td>0.108716</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0.737433</td>
<td>0.234122</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1.055735</td>
<td>0.39472</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>1.494145</td>
<td>0.573393</td>
</tr>
</tbody>
</table>

Table 7.6.2 Results of $-\theta'(0)$ for different values of $Pr$ and $B$ when $A = 0$ and $K = 0$

<table>
<thead>
<tr>
<th>$Pr$</th>
<th>$B$</th>
<th>$-\theta'(0)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>0.1</td>
<td>0.171646</td>
</tr>
<tr>
<td>0.1</td>
<td>0.1</td>
<td>0.17674</td>
</tr>
<tr>
<td>0.5</td>
<td>0.1</td>
<td>0.219637</td>
</tr>
<tr>
<td>1.0</td>
<td>0.1</td>
<td>0.271005</td>
</tr>
<tr>
<td>1.5</td>
<td>0.1</td>
<td>0.314981</td>
</tr>
<tr>
<td>0.7</td>
<td>0</td>
<td>0.303411</td>
</tr>
<tr>
<td>0.7</td>
<td>0.1</td>
<td>0.273324</td>
</tr>
<tr>
<td>0.7</td>
<td>0.1</td>
<td>0.240921</td>
</tr>
</tbody>
</table>

Table 7.6.3 Comparison of present results of skin friction coefficient $f''(0)$ and heat transfer coefficient $\theta'(0)$ with values obtained by R.A. Mohamed [68] and Ziaabakhsh [115] for different values of $K$ when $A = 1$, $B = 0.1$, $Pr = 0.7$ and $Ha = 0$

<table>
<thead>
<tr>
<th>$K$</th>
<th>$f''(0)$ (previous study of et al.)</th>
<th>$-\theta'(0)$ (previous study of et al.)</th>
<th>$f''(0)$ (present study)</th>
<th>$-\theta'(0)$ (present study)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.8893</td>
<td>0.9722</td>
<td>1.8263</td>
<td>0.9236</td>
</tr>
<tr>
<td>0.5</td>
<td>1.6217</td>
<td>0.9575</td>
<td>1.6021</td>
<td>0.9236</td>
</tr>
<tr>
<td>1.0</td>
<td>1.4352</td>
<td>0.9454</td>
<td>1.4012</td>
<td>0.9234</td>
</tr>
<tr>
<td>1.5</td>
<td>1.2966</td>
<td>0.9351</td>
<td>1.2156</td>
<td>0.9142</td>
</tr>
<tr>
<td>2.0</td>
<td>1.1890</td>
<td>0.9216</td>
<td>1.1428</td>
<td>0.9115</td>
</tr>
</tbody>
</table>