CHAPTER VI
1. INTRODUCTION

Siddappa and Bujurke have studied the effect of fluctuating suction to free convection laminar flow of viscous incompressible fluid past a porous vertical plate. Soundalgekar has discussed the free convection effects on the oscillatory flow of an incompressible viscous fluid past an infinite vertical plate with variable suction. Siddappa and Gundappa have investigated the free convection effects on the laminar flow of an incompressible viscoelastic fluid past a porous vertical wall with constant suction.

In this chapter our aim is to study the hydromagnetic free convection effects on laminar flow of an incompressible conducting viscoelastic fluid. The main motivation of this work is to find how the flow past an infinite vertical flat plate in the free convection currents is affected by the variable suction under the influence of uniform transverse magnetic field. The method of solution is the one suggested by Lighthill, Stuart and Nessiha. We have found the velocity distribution, its fluctuating parts, skin friction, its amplitude and phase, temperature distribution, its fluctuating parts, transient temperature and the rate of heat transfer coefficient, its amplitude.
and phase. The flow phenomena have been characterised by the non-dimensional numbers magnetic parameter $M$, Prandtl number $P_r$, Grashoff number $G$ and viscoelastic parameter $S_0$. We have investigated the effects of these parameters on the above said physical quantities for both constant and variable suction.

2. FORMULATION AND SOLUTION OF THE PROBLEM

We consider the flow of an incompressible Rivlin-Ericksen viscoelastic fluid past a porous vertical plate with fluctuating suction under the influence of uniform transverse magnetic field. The $X$-axis is taken along the vertical wall and a straight line perpendicular to that as $Y$-axis. The magnetic field of small intensity $H_0$ is introduced in $Y$ direction. Since the fluid is slightly conducting, the magnetic Reynolds number is much less than unity and hence the induced magnetic field is neglected in comparison with the applied magnetic field (Sparrow and Cess [67]). In the absence of an input electric field the equations governing the flow are

$$\frac{\partial u}{\partial t} + v \frac{\partial u}{\partial y} = g \phi_1 (T - T_\infty) + \frac{\partial^2 u}{\partial y^2} +$$
$$+ \beta \frac{\partial^2}{\partial y^2} \left( \frac{\partial u}{\partial t} + v \frac{\partial u}{\partial y} \right) - \frac{\sigma - \mu_s^2 \mu_e^2}{\rho} u$$  \hspace{1cm} (2.1)
\[
\frac{\partial v}{\partial t} = -\frac{1}{\varrho} \frac{\partial p}{\partial y} + 2 (2\beta + \gamma) \frac{\partial u}{\partial y} \frac{\partial^2 u}{\partial y^2} \tag{2.2}
\]

\[
\frac{\partial v}{\partial y} = 0 \tag{2.3}
\]

\[
\varrho C_p \left( \frac{\partial T}{\partial t} + v \frac{\partial T}{\partial y} \right) = k \frac{\partial^2 T}{\partial y^2} \tag{2.4}
\]

where \(u\) and \(v\) are the velocity components along the axes of coordinates respectively, \(g\) the acceleration due to gravity, \(\beta\) the coefficient of thermal expansion, \(T\) the temperature of the plate, \(T_\infty\) temperature at infinity, \(\nu\) the kinematic viscosity, \(\varrho\) the viscoelasticity, \(t\) the time, \(\sigma\) the electrical conductivity of the fluid, \(\mu_0\) the magnetic permeability, \(\varrho\) the fluid density, \(p\) the fluid pressure, \(\gamma\) the kinematic cross viscosity, \(C_p\) the specific heat at constant pressure and \(k\) the thermal conductivity of the fluid.

We take the fluctuating suction as follows

\[
v = -v_0 (1 + \varepsilon e^{i\omega t}) \tag{2.5}
\]

where \(v_0\) is the mean suction velocity and \(\omega\) is the frequency of the fluctuations. Here \(\varepsilon \ll 1\) and \(A\) is such that \(A \varepsilon \ll 1\).

The boundary conditions are

\[
u = 0, \ T = T_m (1 + \varepsilon e^{i\omega t}) - \varepsilon T_\infty e^{i\omega t} \text{ at } y = 0 \tag{2.6a}
\]

\[
u \to 0, \ T \to T_\infty \text{ as } y \to \infty \tag{2.6b}
\]
where \( T_m \) is the mean value about which the temperature fluctuates. We define the dimensionless quantities

\[
y^* = \frac{v \cdot y}{y_0}, \quad t^* = \frac{t \cdot v^2}{y_0}, \quad u^* = \frac{u}{y_0}, \quad v^* = \frac{v}{y_0}, \quad \omega^* = \frac{\omega}{y_0}
\]

\[
T^* = \frac{T - T_\infty}{T_m - T_\infty}, \quad C = \frac{\lambda g \beta}{v_0^3} (T_m - T_\infty), \quad p^* = \frac{p}{\rho v_0^2},
\]

\[
p = \frac{\rho}{K} C_p \quad \text{and} \quad S = \frac{\beta v_0^2}{y_0^2}
\]

In view of (2.7) the equations (2.1), (2.4) and (2.3)

reduce to (dropping the superscripts *):

\[
\frac{\partial u}{\partial t} - (1 + A \varepsilon e^{i \omega t}) \frac{\partial u}{\partial y} = \sigma T + \frac{\partial^2 u}{\partial y^2} - S \frac{\partial^2 (\frac{\partial u}{\partial t} - (1 + A \varepsilon e^{i \omega t}) \frac{\partial u}{\partial y})}{\partial y^2} = 0
\]

(2.8)

\[
\frac{\partial T}{\partial t} - T(1 + A \varepsilon e^{i \omega t}) \frac{\partial T}{\partial y} = \frac{\partial^2 T}{\partial y^2}
\]

(2.9)

and

\[
v = - (1 + A \varepsilon e^{i \omega t})
\]

(2.10)
\[ S_0 u_1''' + u_1'' + u_1' - A u_1 = - G(1 - T_1) \] (2.16)

\[ S_0 u_2''' + (1 - \omega S_0) u_2'' + u_2' - (\Pi + \omega) u_2 = - S_0 A u_1''' - G(1 - T_2) - A u_1 \] (2.17)

\[ T_1' + P T_1 = 0 \] (2.18)

\[ T_2' + P T_2 = \Pi \omega T_2 = - P A T_1 - \Pi \omega \] (2.19)

where primes denote differentiation with respect to \( y \).

Solving the equations (2.18) and (2.19), using the boundary conditions (2.14) and (2.15) we obtain

\[ T_1 = 1 - e^{-\Pi y} \] (2.20)

\[ T_2 = 1 - e^{-h_2 y} + b (e^{-\Pi y} - e^{-h_2 y}) \] (2.21)

where

\[ b = \frac{AF}{\omega} \quad \text{and} \quad h_2 = \frac{1}{2} \left\{ \frac{F}{F + (P \omega + A)} \right\} \]

Following Lighthill we assume the solution in the form

\[ u_1 = u_{11} + S_0 u_{12} + O(s_o^2) \] (2.22)

\[ u_2 = u_{21} + S_0 u_{22} + O(s_o^2) \] (2.23)

Substituting (2.22) and (2.23) in (2.16) and (2.17) and equating the coefficients of \( s_o \), we obtain
\[ u_{11}^{n} + u_{11}^{i} - M u_{11} = - G (1 - T_{1}) \]  
(2.24)

\[ u_{12}^{n} + u_{12}^{i} - M u_{12} = - u_{11}^{iii} \]  
(2.25)

\[ u_{21}^{n} + u_{21}^{i} - (M + i \omega) u_{21} = - A u_{1}^{i} - G(1 - T_{2}) \]  
(2.26)

\[ u_{22}^{n} + u_{22}^{i} - (M + i \omega) u_{22} = - A u_{1}^{n} - u_{21}^{iii} + i \omega u_{21}^{n} \]  
(2.27)

The corresponding boundary conditions on \( u_{11}, u_{12}, u_{21}, \) and \( u_{22} \) are

\[ u_{11} = u_{12} = u_{21} = u_{22} = 0 \text{ at } y = 0 \]  
(2.28a)

\[ u_{11}, u_{12}, u_{21}, u_{22} \rightarrow 0 \text{ as } y \rightarrow \infty \]  
(2.28b)

Solving the equations (2.24) to (2.27) with the conditions in (2.28) and expressions for \( T_{1} \) and \( T_{2} \) from (2.20) and (2.21), we get

\[ u_{1} = a(e^{-h_{1}y} - e^{-h_{2}y}) \]  
(2.29)

\[ u_{2} = (a_{1} + s_{o} a_{4})(e^{-h_{1}y} - e^{-h_{3}y}) + (a_{2} + s_{o} a_{5})(e^{-h_{1}y} - e^{-h_{2}y}) - (a_{3} + s_{o} a_{6})(e^{-h_{2}y} - e^{-h_{3}y}) \]  
(2.30)

where

\[ a = \frac{G}{(P^{2} - P - M)(1 + \frac{s_{o} P^{3}}{(P^{2} - P - M)})} \]

\[ h_{1} = \frac{1}{2} \left\{ 1 + (4M + 1) \right\} \]
\[ h_3 = \frac{1}{2} \left\{ 1 + \left(1 + 4M + 4i\omega \right)^{1/2} \right\} \]

\[ a_1 = \frac{Gb - AaP}{P^2 - P - (M + i\omega)} \]

\[ a_2 = \frac{Aah_2}{h_1^2 - h_1 - (M + i\omega)} \]

\[ a_3 = \frac{G(1 + b)}{h_2^2 - h_2 - (M + i\omega)} \]

\[ a_4 = \frac{(a_1 P^3 - AaP^3 + a_1 i\omega P^2)}{(P^2 - P - (M + i\omega))} \]

\[ a_5 = \frac{(Aah_1^3 + a_2 h_1^3 + a_2 i\omega h_1^2)}{(h_1^2 - h_1 - (M + i\omega))} \]

\[ a_6 = \frac{(a_3 h_2^3 + a_3 h_2^2 i\omega)}{(h_2^2 - h_2 - (M + i\omega))} \]

Now the real and imaginary parts of \( u_2(y) = u_x + i u_y \) are given by

\[ u_x = \xi_1 (e^{-h_1 Y} - c_1) - \xi_2 (e^{-P Y} - c_2) - \xi_3 c_3 + (\xi_4 - \xi_3) c_2 + \xi_6 c_4 \]

\[ u_y = (\xi_1 - \xi_2) c_2 + \xi_5 (e^{-h_1 Y} - c_1) - \xi_4 (e^{-P Y} - c_2) - \xi_3 c_4 + \xi_6 c_3 \]
\[ f_1 = \left( \frac{b_7}{b_9} + \frac{b_{10}}{b_{12}} \right) \]
\[ f_2 = \left( \frac{b_1}{b_3} + \frac{b_4}{b_6} \right) \]
\[ f_3 = \left( \frac{b_{13}}{b_{15}} + \frac{b_{16}}{b_{18}} \right) \]
\[ f_4 = \left( \frac{b_2}{b_3} + \frac{b_5}{b_6} \right) \]
\[ f_5 = \left( \frac{b_8}{b_9} + \frac{b_{11}}{b_{12}} \right) \]
\[ f_6 = \left( \frac{b_{14}}{b_{15}} + \frac{b_{17}}{b_{18}} \right) \]

\[ b_1 = A \left\{ (P^2 - P - M)(1 + S_o P^2)ap - GP \right\} \]
\[ b_2 = AP \left\{ \frac{G}{\omega} (P^2 - P - M) + \omega a(1 + S_o P^2) \right\} \]
\[ b_3 = (P^2 - P - M)^2 + \omega^2 \]

\[ b_4 = APS_o \left\{ (ap^3 - GP^2)((P^2 - P - M)^2 - \omega^2) - \\
- 2 \omega (P^2 - P - M)(\frac{GP^3}{\omega} + \omega aP^2) \right\} \]
\[ b_5 = APS_o \left\{ (\frac{GP^3}{\omega} + \omega aP^2)((P^2 - P - M)^2 - \omega^2) + \\
+ 2 \omega (P^2 - P - M)(ap^3 - GP^2) \right\} \]
\[ b_6 = \left\{ (F^2 - F - M)^2 - \omega^2 \right\}^2 + 4 \omega^2 (F^2 - F - M)^2 \]

\[ b_7 = Aa_1 (1 + s_0 h_1^2) (h_1^2 - h_1 - M) \]

\[ b_8 = Aa_1 \omega (1 + s_0 h_1^2) \]

\[ b_9 = (h_1^2 - h_1 - M)^2 + \omega^2 \]

\[ b_{10} = \frac{Aa_1^3}{s_0} \left\{ h_1 ((h_1^2 - h_1 - M)^2 - \omega^2) - 2 \omega^2 (h_1^2 - h_1 - M) \right\} \]

\[ b_{11} = \frac{Aa_1^3}{s_0} \left\{ \omega ((h_1^2 - h_1 - M)^2 - \omega^2) + 2h_1 \omega (h_1^2 - h_1 - M) \right\} \]

\[ b_{12} = \left\{ (h_1^2 - h_1 - M)^2 - \omega^2 \right\}^2 + 4 \omega^2 (h_1^2 - h_1 - M)^2 \]

\[ b_{13} = G(d_1 - \frac{A_F}{\omega} d_2) \]

\[ b_{14} = - G(\frac{A_F}{\omega} d_1 + d_2) \]

\[ b_{15} = d_1^2 + d_2^2 \]

\[ b_{16} = Gs_0 \left\{ (d_3 + \frac{A_F}{\omega} d_4)(d_1^2 - d_2^2) + 2a_1 d_2 (a_4 - \frac{A_F}{\omega} d_3) \right\} \]

\[ b_{17} = Gs_0 \left\{ (d_4 - \frac{A_F}{\omega} d_3)(d_1^2 - d_2^2) - 2a_1 d_2 (a_3 + \frac{A_F}{\omega} d_4) \right\} \]

\[ b_{18} = (d_1^2 - d_2^2)^2 + 4a_1^2 d_2^2 \]
\[ c_1 = \exp \left\{ -\frac{\eta}{2} \left( 1 + \xi \cos \eta \right) \right\} \cos \left( \frac{\eta}{2} \xi \sin \eta \right) \]

\[ c_2 = \exp \left\{ -\frac{\eta}{2} \left( 1 + \xi \cos \eta \right) \right\} \sin \left( \frac{\eta}{2} \xi \sin \eta \right) \]

\[ c_3 = \exp \left\{ -\frac{\eta}{2} \left( P + r \cos \Theta \right) \right\} \cos \left( \frac{\eta}{2} \xi \sin \eta \right) - \]

\[ - \exp \left\{ -\frac{\eta}{2} \left( 1 + \xi \cos \eta \right) \right\} \cos \left( \frac{\eta}{2} \xi \sin \eta \right) \]

\[ c_4 = \exp \left\{ -\frac{\eta}{2} \left( 1 + \xi \cos \eta \right) \right\} \sin \left( \frac{\eta}{2} \xi \sin \eta \right) - \]

\[ - \exp \left\{ -\frac{\eta}{2} \left( P + r \cos \Theta \right) \right\} \sin \left( \frac{\eta}{2} \xi \sin \eta \right) \]

\[ d_1 = r^2 + (r^2 \cos^2 \Theta - r^2 \sin^2 \Theta) + (2P - 1) \rho \cos \Theta - (P + M) \]

\[ d_2 = (P + \rho \cos \Theta) 2 \rho \sin \Theta - (\omega + \rho \sin \Theta) \]

\[ d_3 = (P^3 + r^3 \cos^3 \Theta + 3P^2 \rho \cos \Theta - 3P \rho^2 \sin^2 \Theta) - \]

\[ - \omega (2r^2 \cos \Theta \sin \Theta + 2P \rho \sin \Theta) \]

\[ d_4 = (3r^3 \cos^2 \Theta \sin \Theta - r^3 \sin^3 \Theta + 3P^2 \rho \cos \Theta \sin \Theta) + \]

\[ + \omega (P^2 + r^2 \cos^2 \Theta - r^2 \sin^2 \Theta + 2P \rho \cos \Theta) \]

\[ \xi \cos \eta = \left[ \frac{d_3 + (4M + 1)}{2d_5} \right]^{\frac{1}{2}} \]

\[ \xi \sin \eta = \left[ \frac{d_3 - (4M + 1)}{2d_5} \right]^{\frac{1}{2}} \]
\[ d_5 = \left\{ (4M + 1)^2 + 16\omega^2 \right\}^{1/2} \]

\[ r \cos \theta = \left[ \frac{p}{2} \left\{ (F^2 + 16\omega^2) + p \right\} \right]^{1/2} \]

\[ r \sin \theta = \left[ \frac{p}{2} \left\{ (F^2 + 16\omega^2)^{1/2} - p \right\} \right]^{1/2} \]

Hence from (2.12) the real part of \( u(y, t) \) is given by

\[ u(y, t) = u_1(y) + \varepsilon (u_2 \cos \omega t - u_1 \sin \omega t) \quad (2.31) \]

**Skin friction:**

The expression for skin friction on the plate is given by

\[ \tau = \left[ (\delta + \beta \frac{\partial}{\partial t}) \frac{\partial u}{\partial y} \right] y = 0 \quad (2.32) \]

In view of transformations (2.7), the equation (2.32) yields (after dropping superscripts *)

\[ \tau = v_0^2 \left[ (1 - s_0 \frac{\partial}{\partial t}) \frac{\partial u}{\partial y} \right] y = 0 \]

\[ = v_0^2 \left[ a(f - h_1) + \frac{\varepsilon}{2} \left| B \right| \cos (\omega t + \theta) \right] \quad (2.33) \]

where the amplitude \( \left| B \right| \) and the phase \( \theta \) of the skin friction are given by

\[ \left| B \right| = (B_2^2 + B_1^2)^{1/2} \quad (2.34) \]

and

\[ \theta = \tan^{-1} \left( \frac{B_1}{B_2} \right) \quad (2.35) \]
where

\[ B_r = (f_1 + f_5 s_0 \omega)(1 + \xi \cos \gamma - 2h_1) - \]

\[ - (f_2 + f_4 s_0 \omega)(1 + \xi \cos \gamma - 2p) + \]

\[ + \left\{ (f_4 - f_5) + (f_1 - f_2)s_0 \omega \right\} \xi \sin \gamma - \]

\[ - (f_3 + f_6 s_0 \omega)(1 + \xi \cos \gamma - p - r \cos \theta) + \]

\[ + (f_6 - f_3 s_0 \omega)(\xi \sin \gamma - \sin \theta) \]

\[ B_1 = (f_5 - f_1 s_0 \omega)(1 + \xi \cos \gamma - 2h_1) + \]

\[ + (f_2 s_0 \omega - f_4)(1 + \xi \cos \gamma - 2p) + \]

\[ + \left\{ (f_1 - f_2) - (f_4 - f_5)s_0 \omega \right\} \xi \sin \gamma + \]

\[ + (f_3 s_0 \omega - f_6)(1 + \xi \cos \gamma - p - r \cos \theta) - \]

\[ - (f_3 + f_6 s_0 \omega)(\xi \sin \gamma - \sin \theta) \]

Temperature distribution:

From the equation (2.13), with the expressions (2.20) and (2.21), the real part of \( T(y, t) \) is given by

\[ T(y, t) = e^{-pt} + \epsilon (T_r \cos \omega t - T_1 \sin \omega t) \quad (2.36) \]

where the fluctuating parts of the temperature are given by
\[ T_r = \exp \left\{ -\frac{1}{2} (F + r\cos \theta) \right\} \cos \left( \frac{y}{2} r\sin \theta \right) - \frac{\Delta P}{\omega} \exp \left\{ -\frac{1}{2} (F + r\cos \theta) \right\} \sin \left( \frac{y}{2} r\sin \theta \right) \]

\[ T_y = \frac{\Delta P}{\omega} e^{-\omega y} - \exp \left\{ -\frac{1}{2} (F + r\cos \theta) \right\} \sin \left( \frac{y}{2} r\sin \theta \right) - \frac{\Delta P}{\omega} \exp \left\{ -\frac{1}{2} (F + r\cos \theta) \right\} \cos \left( \frac{y}{2} r\sin \theta \right) \]

The transient temperature \( \omega t = \frac{\pi}{2} \) is given by

\[ T = \exp \left\{ -\omega y \right\} - e T_y. \]

**Heat transfer**

The rate of heat transfer from the plate is given by

\[ q = K \left( \frac{\partial T}{\partial y} \right) y = 0 \tag{2.37} \]

In view of transformations (2.7), the equation (2.37)

(after dropping superscripts *) yields

\[ q = \frac{K G v^4}{\sqrt{2} g \beta_i} \left( \frac{\partial E}{\partial y} \right) y = 0 \]

\[ = - \frac{K G v^4}{\sqrt{2} g \beta_i} \left[ F + \varepsilon \left| B^* \right| \cos (\omega t + \delta) \right] \]

where the amplitude \( \left| B^* \right| \) and the phase \( \delta \) of the rate of heat transfer are given by

\[ B^* = \left( B_r^2 + B_i^2 \right)^{1/2} \]

and

\[ \delta = \tan^{-1} \left( \frac{B_i}{B_r} \right) \]

where
\[ D^* = \frac{P + r \cos \theta}{2} + \frac{AP}{2} r \sin \theta \]

\[ B_1^* = \frac{AR}{\omega} + \frac{r \sin \theta}{2} - \frac{AR}{2\omega} (r + r \cos \theta) \]

3. CONCLUSIONS

**Velocity distribution**: (Figures 1 to 12)

We have investigated the effects of magnetic parameter \( M \), Prandtl number \( P \), Grashoff number \( G \) and viscoelastic parameter \( S_0 \) on the fluctuating parts \( u_\tau \), \( u_\phi \) of velocity and the velocity distribution \( u \). In figure 1, \( u_\tau \) is plotted against \( y \) for different values of magnetic parameter \( M \), taking \( A = 0 \) and \( A = 0.2 \). It is observed that \( u_\tau \) decreases with the increase in \( M \). At points very close to the plate \( u_\tau \) increases sharply and then decreases in the same manner. But this increase/decrease in velocity is not very sharp at points far away from the plate. It is further observed that in the case of constant suction, \( u_\tau \) increases with the increase in \( M \) at points far away from the plate. In figure 2, \( u_\tau \) is drawn against \( y \) for different \( P \). We have noticed that \( u_\tau \) decreases with the increase in \( P \) in the region very close to the plate and this trend gets reversed at points away from the plate.

In figure 3, \( u_\tau \) is plotted against \( y \) for different values of \( G \). We have seen that \( u_\tau \) increases with the increase in \( G \) at points very close to the plate and this trend gets reversed at points far away from the plate. In figure 4, \( u_\tau \) is drawn
against $y$ for different values of $S_0$. It is clear from the
figure that $u_1$ increases with the increase in $S_0$. Figure 5
shows the profiles of $u_1$ against $y$ for different values of $M$.
It is observed that $u_1$ decreases as $M$ increases. For a
particular value of $M$, it is seen that $u_1$ decreases at points
very close to the plate and then it increases. In figure 6, $u_1$
is plotted against $y$ for different values of $P$. We have
observed that $u_1$ increases with the increase in $P$. Figures
7 and 8 give the profiles of $u_1$ for different values of $G$
and $S_0$ respectively. It is noticed that $u_1$ decreases as $G$
or $S_0$ increases. For a particular value of $G$ or $S_0$, $u_1$ first
decreases and then increases. Figures 9 and 10 show the
velocity profiles for different values of $M$ and $P$ respectively.
It is observed that the velocity decreases as $M$ or $P$ increases.
It is also seen that the velocity first increases and then
decreases for a particular value of $M$ or $P$. In figures 11
and 12, the velocity is plotted against $y$ for different values
of $G$ and $S_0$ respectively. It is noticed that the velocity
increases with the increase in $G$ whereas the velocity decreases
with the increase in $S_0$.

Skin friction: (Figures 13 to 18)

In figure 13, the skin friction $\tau$ is plotted against $M$
for different values of $G$. It is observed that $\tau$ decreases
with the increase in $M$ whereas it increases as $G$ increases.
In figure 14, the skin friction $\tau$ is plotted against $P$ for
different values of $S_0$. It is seen that $\tau$ decreases with
the increase in $F$ when $S_o = 0.05$ whereas it increases first
and then decreases for values of $S_o > 0.05$. The effect of $S_o$
on $\tau$ is shown in figure 14. In figure 15, $|B|$, the amplitude
of the skin friction is plotted against $M$ for different values
of $C$. It is seen that $|B|$ increases with the increase in $M$
in the case of constant suction whereas it decreases in the
case of variable suction. It is also seen that $|B|$ increases
with the increase in $C$ in both the cases of constant and
variable suction. In figure 16, $|B|$ is plotted against $P$
for different values of $S_o$. It is observed that $|B|$ decreases
as $P$ increases in the case of constant suction whereas it
decreases for small values of $P$ and increases for higher values
of $P$ in the case of variable suction. It is also observed that
$|B|$ increases with the increase in $S_o$ in both the cases of
constant and variable suction. In figure 17, $\tan \theta$, the
phase of the skin friction is plotted against $M$ for different
values of $C$. In both the constant and variable suction, it
is seen that $\tan \theta$ decreases as $M$ increases. It is also seen
that $\tan \theta$ increases with the increase in $C$ in both the cases
and
of constant and variable suction. In figure 18, $\tan \theta$ is drawn
against $P$ for different values of $S_o$. It is observed that
$\tan \theta$ increases for small values of $P$ and decreases for higher
values of $P$ in the case of variable suction whereas it increases
as $P$ increases in the case of constant suction. It is also
observed that $\tan \theta$ decreases as $S_o$ increases in both the cases
of constant and variable suction.
Temperature distribution: (Figures 19 to 22)

In figure 19 and 20, the fluctuating parts \( T_x \) and \( T_y \) of the temperature distribution are plotted against \( y \) for different values of \( P \). It is seen that \( T_x \) increases with the increase in \( P \). A close look at the figure reveals the fact that \( T_x \) decreases sharply at points very near the plate. Figure 20 shows that \( T_y \) increases with the increase in \( P \) at points very close to the plate and this trend gets reversed far away from the plate. Figures 21 and 22 illustrate the effect of \( P \) on the transient temperature and the temperature distribution. It is observed that both the transient temperature and the temperature decrease with the increase in \( P \).

The Rate of heat transfer: (Figures 23 to 25)

Figure 23 shows the effects of \( P \) and \( \omega \) (frequency of the fluctuation) on the coefficient of heat transfer \( q \). It is seen that \( q \) decreases as \( P \) increases whereas \( q \) increases first for small values of \( \omega \) and then decreases for higher values of \( \omega \). Figure 24 illustrates the effects of \( P \) and \( \omega \) on \( |B^*| \), the amplitude of \( q \). It is noticed that \( |B^*| \) increases as \( P \) or \( \omega \) increases. Figure 25 shows the effects of \( P \) and \( \omega \) on \( \tan \phi \), the phase of \( q \). It is seen that \( \tan \phi \) decreases with the increase in \( P \) whereas it increases as \( \omega \) increases.
FIG. 4: $y$ plotted against $x$ for different values of $S_0$

$S_0 = 0.15$

$A = 0.2$ ——— $A = 0$

FIG. 3: $y$ plotted against $x$ for different values of $G$

$G = 3$

$A = 0.2$ ——— $A = 0$
FIG. 6: Plotted against y for different values of P.

FIG. 5: Plotted against y for different values of M.
FIG. 7 $u_i$ plotted against $y$ for different values of $G$

FIG. 8 $u_i$ plotted against $y$ for different values of $S_0$
Fig. 10 Velocity profiles for different values of P.

Fig. 9 Velocity profiles for different values of M.
FIG. 15 $|B|$ plotted against $M$
for different values of $G$

FIG. 16 $|B|$ plotted against $P$
for different values of $S_0$
FIG. 17 $\tan \theta$ plotted against $M$ for different values of $G$

- $A=0.2$
- $A=0$

$G = \frac{2}{3}$

FIG. 18 $\tan \theta$ plotted against $P$ for different values of $S_0$

- $A=0.2$
- $A=0$

Values of $0.05, 0.1, 0.15, 0.2$
FIG. 21 Transient temperature profiles for different values of $p$

FIG. 22 Temperature profiles for different values of $p$
FIG. 23: $q$ plotted against $P, \omega$

FIG. 24: $|B^*|$ plotted against $P, \omega$

FIG. 25: $\tan \theta$ plotted against $P, \omega$

$A = 0.2$ (solid line), $A = 0$ (dashed line)

$P$, $\omega$