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Page(s): 1-4

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Page(s): 19-26

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Page(s): 95-98

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Page(s): 104-107

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The Improvement Of Local Cultivar Sorghum (Shweni-15) With The Aim Of Bioethanol Production Through Gamma Radiation

Page(s): 108-111

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THE EFFECT OF PRANDTL NUMBER AND VISCOSITY VARIABLE ON FREE CONVECTION BOUNDARY LAYER FLOWOF A VISCOELASTIC FLUID PAST AN ELLIPTIC CYLINDER

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Abstract- Convection is the convective heat transfer from one place to another place which is caused by the movement of fluid. Analytical solution of the convection equation is developed from nonlinear of Navier-Stokes. This paper considers the steady boundary layer flow and heat transfer of viscoelastic fluid past an elliptic cylinder. The heat transfer comes from the surface is proportional to the both of temperature on surrounding cylinder surface and the velocity of the fluid. The governing equations are developed from continuity, momentum, and energy conservation. Further, those equations are transformed into boundary layer equations. The boundary equations further are transformed into nondimensional form. The similarity equations is applied to solve the non-dimensional form easily. We further solve the equations numerically by using the finite difference method. The numerical results show that the temperature and the velocity distributions decrease when the Prandtl number increases. For the variation of the viscosity variable, the temperature distributions increase and the velocity distributions decrease when the viscosity variable increases.

Keywords- viscoelastic fluid, Navier-Stokes equations, boundary layer theory, finite difference method

I. INTRODUCTION

Convection is the convective heat transfer from one place to another place which is caused by the movement of fluid. In generally, there are two convective forms, such as free convection and forced convection. There are many research for types of convection, especially for the application of the technique.
Analytical solution of the convection equation is developed from nonlinear of Navier-Stokes and energy equation. Boundary layer equation is an initial solution to calculate that problems. Boundary layer is a thin layer on a solid surface where the fluid flow is influenced by the viscosity and inertia force of the cylinder. The governing equations are developed from continuity, momentum, and energy conservation.
Viscoelastic fluid is type of non-Newtonian fluid whose viscos and elastic characteristic. Now, this type has attracts many researchers because the application of this fluid is very important, especially for oil drilling, food and paper industry [1].This paper considers the steady boundary layer flow and heat transfer of non-Newtonian fluid past an elliptic cylinder.

II. PROBLEM FORMULATION

We consider steady free convection boundary layer flow past an elliptic cylinder in a viscoelastic fluid. Fig. 1 illustrates the physical model and the coordinate system of the elliptic cylinder, as in [2] and [3]. It is assumed that the constant heat flux of the surface cylinder is q_w and the ambient fluid is T_∞, where $T > T_\infty$ for heated cylinder. The governing equations are developed from mass, momentum, and energy conservation, as follows [1]:

Continuity equation:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \qquad (1)$$

Momentum equation:

$$\rho\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) = -\frac{\partial P}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + F_x$$
$$\rho\left(u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y}\right) = -\frac{\partial P}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + F_y \qquad (2)$$

Energy equation:

$$\left(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}\right) = \alpha\frac{\partial^2 T}{\partial y^2} + \frac{Q_0}{\rho C_p}(T - T_\infty) \qquad (3)$$

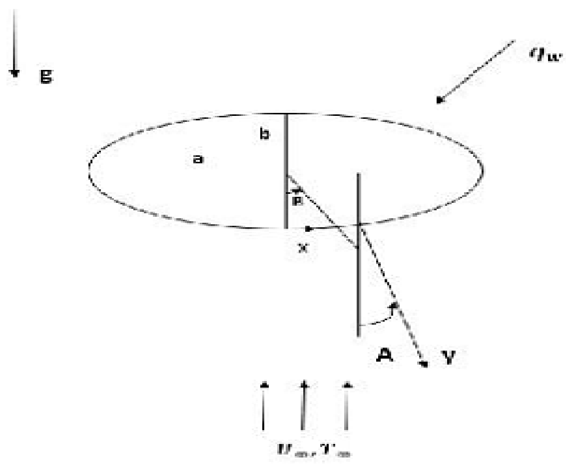

Fig 1. Physical model and coordinate system

In Eqn. (2), the effect of viscous forces in fluid ( )is solved by using Walter-B tensor, defined as [1]:

$$\tau_{ij} = \mu_0(2d_{ij}) - k_0(2\hat{d}_{ij}) \quad (4)$$

where

$$\hat{d}_{ij} = \boldsymbol{V}.\nabla(d_{ij}) - (d_{ij})(\nabla\mathbf{V})^T - \nabla.\boldsymbol{V}(d_{ij}) \quad (5)$$

and

$$d_{ij} = \frac{1}{2}\left[\frac{\partial \boldsymbol{V}_j}{\partial x_i} + \frac{\partial \boldsymbol{V}_i}{\partial x_j}\right] \quad (6)$$

Substitute Eqn. (4) into Eqn. (6) and definition $\boldsymbol{F} = \rho\boldsymbol{g}$, where $\boldsymbol{F} = (F_x, F_y, 0)$ and $\boldsymbol{g} = (-g_x, -g_y, 0)$, the following equations are obtain:

Momentum equation for x-coordinate:

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{1}{\rho}\frac{\partial P}{\partial x} + \frac{\mu_0}{\rho}\left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right] - \frac{k_0}{\rho}\left[u\left(\frac{\partial^3 u}{\partial x^3} + \frac{\partial^3 u}{\partial x \partial y^2}\right) + v\left(\frac{\partial^3 u}{\partial x^2 \partial y} + \frac{\partial^3 u}{\partial y^3}\right) - \frac{\partial u}{\partial y}\left(\frac{\partial^2 u}{\partial x \partial y} + \frac{\partial^2 v}{\partial x^2}\right) - 2\frac{\partial v}{\partial x}\frac{\partial^2 u}{\partial x \partial y} - \frac{\partial u}{\partial x}\left(3\frac{\partial^2 u}{\partial x^2} - \frac{\partial^2 u}{\partial y^2}\right)\right] + \frac{1}{\rho}F_x \quad (7)$$

Momentum equation for y-coordinate:

$$u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -\frac{1}{\rho}\frac{\partial P}{\partial y} + \frac{\mu_0}{\rho}\left[\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right] - \frac{k_0}{\rho}\left[u\left(\frac{\partial^3 v}{\partial x^3} + \frac{\partial^3 v}{\partial x \partial y^2}\right) + v\left(\frac{\partial^3 v}{\partial x^2 \partial y} + \frac{\partial^3 v}{\partial y^3}\right) + \frac{\partial u}{\partial x}\left(3\frac{\partial^2 v}{\partial y^2} - \frac{\partial^2 v}{\partial x^2}\right) - \frac{\partial v}{\partial x}\left(\frac{\partial^2 v}{\partial x \partial y} + \frac{\partial^2 u}{\partial y^2}\right) - 2\frac{\partial u}{\partial y}\frac{\partial^2 v}{\partial x \partial y}\right] + \frac{1}{\rho}F_x \quad (8)$$

Then, under the usual Bousinesq, boundary layer approximation, and defined [3]:

$$g_x = -g\sin A$$

where

$$\sin A = \frac{b}{a}\frac{\sin B}{(1 - e^2\sin^2 B)^{1/2}}$$

The equations for continuity, momentum, and energy take the following form:

Continuity equation:

$$\frac{\partial \bar{u}}{\partial \bar{x}} + \frac{\partial \bar{v}}{\partial \bar{y}} = 0 \quad (9)$$

Momentum equation:

$$\bar{u}\frac{\partial \bar{u}}{\partial \bar{x}} + \bar{v}\frac{\partial \bar{u}}{\partial \bar{y}} = \nu\left[\frac{\partial^2 \bar{u}}{\partial \bar{y}^2}\right] + g\beta(\bar{T} - \bar{T}_\infty)\sin A - \frac{k_0}{\rho}\left[\bar{u}\left(\frac{\partial^3 \bar{u}}{\partial \bar{x}\partial \bar{y}^2}\right) + \bar{v}\frac{\partial^3 \bar{u}}{\partial \bar{y}^3} - \frac{\partial \bar{u}}{\partial \bar{y}}\left(\frac{\partial^2 \bar{u}}{\partial \bar{y}\partial \bar{x}}\right) + \frac{\partial \bar{u}}{\partial \bar{x}}\left(\frac{\partial^2 \bar{u}}{\partial \bar{y}^2}\right)\right] \quad (10)$$

Energy equation:

$$\left(\bar{u}\frac{\partial \bar{T}}{\partial \bar{x}} + \bar{v}\frac{\partial \bar{T}}{\partial \bar{y}}\right) = \alpha\frac{\partial^2 \bar{T}}{\partial \bar{y}^2} + \frac{Q_0}{\rho C_p}(\bar{T} - \bar{T}_\infty)$$

Subject to the Boundary Conditions:

$$\bar{u} = \bar{v} = 0, \quad \frac{\partial T}{\partial \bar{y}} = -\frac{q_w}{k} \quad on\ \bar{y} = 0$$

$$\bar{u} = 0, \quad \frac{\partial \bar{u}}{\partial \bar{y}} = 0, \quad \bar{T} = \bar{T}_\infty \quad as \quad y \to \infty$$

Below are the following non-dimensional variables:

$$v = \frac{a}{\nu}Gr^{-1/4}v, \quad \theta = (T - T_\infty)/(q_w a/k)$$

$$x = \frac{\bar{x}}{a}, \quad y = Gr^{1/4}\left(\frac{\bar{y}}{a}\right), \quad u = \frac{a}{\nu}Gr^{-1/2}\bar{u} \quad (12)$$

Substitution Eqn. (12) into Eqn. (9) to (11) lead to the following non-dimensional equations:

Continuity equation:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (13)$$

Momentum equation:

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} - K\left[\frac{\partial}{\partial x}\left(u\frac{\partial^2 u}{\partial y^2}\right) + v\frac{\partial^3 u}{\partial y^3} - \frac{\partial u}{\partial y}\frac{\partial^2 u}{\partial y \partial x}\right] - \theta\sin A \quad (14)$$

Energy equation:

$$u\frac{\partial \theta}{\partial x} + v\frac{\partial \theta}{\partial y} = \frac{1}{Pr}\frac{\partial^2 \theta}{\partial y^2} + \gamma\theta \quad (15)$$

Subject to the Boundary Conditions:

$$u = v = 0,\ \theta' = -1 \quad on \quad y = 0$$
$$u = 0,\ \frac{\partial u}{\partial y} = 0,\ \theta = 0 \quad as \ y \to \infty \quad (16)$$

and

$$Pr = \frac{v}{\alpha},\ K = \frac{k_0 Gr^{1/2}}{\rho a^2},\ \gamma = \frac{a^2 Q_0}{v C_p Gr^{1/2}}$$

Where Pr is Prandtl number, K is viscosity variable, γ is heat generation, ν is kinematic viscosity, α is thermal diffusivity.

III. SOLUTION PROCEDURES

In order to solve Eqn. (13) to (15) according to the Boundary Condition Eqn. (16), the following variables are assumed [4]:

$$\psi = x f(x, y),\quad \theta = \theta(x, y) \quad (17)$$

where ψ is the stream function defined as [3] and [4]:

$$u = \frac{\partial \psi}{\partial y},\quad v = -\frac{\partial \psi}{\partial x} \quad (18)$$

By substituting Eqn. (17) and (18) into Eqns. (13) to (15), we obtain:

$$\frac{\partial f}{\partial y} = 0 \quad (19)$$

$$\frac{\partial^3 f}{\partial y^3} + f\frac{\partial^2 f}{\partial y^2} - \left(\frac{\partial f}{\partial y}\right)^2 - x\left(\frac{\partial f}{\partial y}\frac{\partial^2 f}{\partial x \partial y} - \frac{\partial f}{\partial x}\frac{\partial^2 f}{\partial y^2}\right) + \theta \sin A - Kx\left(\frac{\partial^2 f}{\partial x \partial y}\frac{\partial^3 f}{\partial y^3} + \frac{\partial f}{\partial y}\frac{\partial^4 f}{\partial x \partial y^3} - \frac{\partial f}{\partial x}\frac{\partial^4 f}{\partial y^4} - \frac{\partial^2 f}{\partial y^2}\frac{\partial^3 f}{\partial x \partial y^2}\right) - K\left(2\frac{\partial f}{\partial y}\frac{\partial^3 f}{\partial y^3} - f\frac{\partial^4 f}{\partial y^4} - \frac{\partial^2 f}{\partial y^2}\frac{\partial^2 f}{\partial y^2}\right) = 0 \quad (20)$$

$$\frac{1}{Pr}\frac{\partial^2 \theta}{\partial y^2} + f\frac{\partial \theta}{\partial y} + \gamma\theta - x\left(\frac{\partial f}{\partial y}\frac{\partial \theta}{\partial x} - \frac{\partial f}{\partial x}\frac{\partial \theta}{\partial y}\right) = 0 \quad (21)$$

With respect to the following Boundary Conditions:

$$f = \frac{\partial f}{\partial y} = 0,\ \theta' = -1 \quad on\ y = 0$$
$$\frac{\partial f}{\partial y} = 0,\ \frac{\partial^2 f}{\partial y^2} = 0,\ \theta = 0 \quad as\ y \to \infty \quad (22)$$

At the lower stagnation point of the cylinder, $x \approx 0$, Eqns. (19) to (21) are reduced to the following ordinary differential equation:

$$f''' + ff'' - (f')^2 + \theta \sin A + K(2f'f''' - ff^{(4)} - (f'')^2) = 0 \quad (23)$$

$$\frac{1}{Pr}\theta'' + f\theta' + \gamma\theta = 0 \quad (24)$$

With the Boundary Conditions:

$$f(0) = f'(0) = 0,\quad \theta'(0) = -1$$
$$f'(\infty) = 0,\quad f''(\infty) = 0,\ \theta(\infty) = 0 \quad (25)$$

Where primes denote the differentiation with respect to Y.

IV. RESULT AND DISCUSSION

The system of Equation (23) and (24) are solved numerically for some values of the Prandtl numbers Pr= 0.04, 0.07, 0.073, 0.075 and the viscosity variable K = 0.1, 0.101, 0.102, 0.103 using the finite difference method [5-7].

$$f' = p$$
$$f = p\Delta y \quad (26)$$

By substituting Eqn. (26) into Eqn. (23), the following equations are obtained:

$$p'' + p\Delta y p' - p^2 + \theta \sin A - K(2pp'' - p\Delta y p''' - (p')^2) = 0 \quad (27)$$

The present results for the wall temperature are compared with previous research in order to validate the numerical results. The comparison show that the numerical solutions (Table 1) obtained by the present authors concurs very well with those of previous authors [8].

Pr	θ(0)			Error	
	Salleh dan Nazar (2010)	Sarif (2013)	Present result	Salleh dan Nazar (2010)	Sarif (2013)
0.5	92.1979	92.1980	92.1916	0.0063	0.0064
1	35.4701	35.4701	35.4471	0.023	0.023
2	15.7804	15.7803	15.7730	0.0074	0.0073
3	10.5357	10.5357	10.5345	0.0012	0.0012

Table 1. Comparison of the present numerical results for wall temperature at $K = 0$ and $\gamma = 1$

Beside that comparison of the present result with those of previous works on wall temperature, the comparison on temperature and velocity depicted in Fig. 2 and 3. The variation of temperature and velocity with various values of Prandtl numbers Pr= 0.04, 0.07, 0.073, 0.075 with the fixed Values Y = 1 and K= 0.05 are illustrated in Fig. 2(a) and 2(b). From the figures. We can see that the temperature and velocity decrease when the 4 Prandtl number increases.This is as expected because the increasing of Prandtl number will affect the kinematic viscosity and thermal diffusivity of the fluid.

The distribution of temperature and velocity profile with various viscoelastic parameter K = 0.1, 0.101, 0.102, 0.103 with fixed value Pr= 0.05 and Y= 1 can be seen in Fig. 3(a) and 3(b). Those figures obtain that the temperature distribution increase when the viscoelastic parameter increases, otherwise the distribution of velocity decrease when the viscosity variable increases. It is happen because of the friction forces in viscoelastic fluid. The velocity distributions decease when the friction forces increases, while the opposite behavior is observed for the temperature profile.

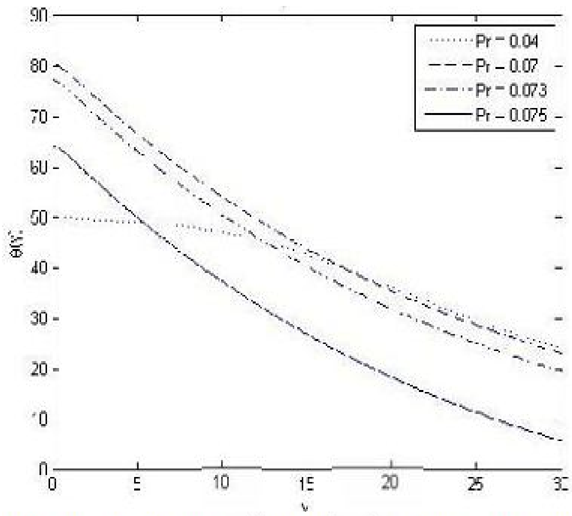

Fig. 2(a) Temperature distribution for various value of Pr at $\gamma = 1$ and $K = 0.05$

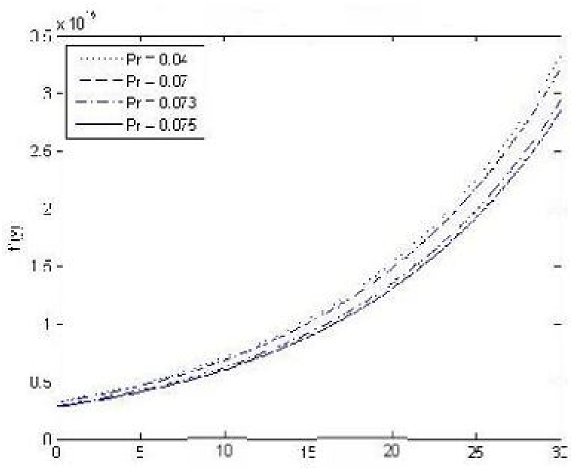

Fig. 2(b) Velocity distribution for various value of Pr at $\gamma = 1$ and $K = 0.05$

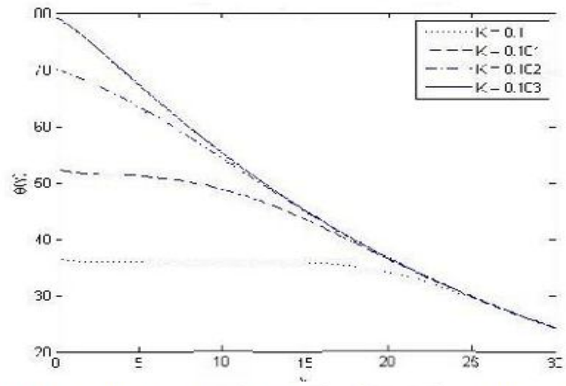

Fig. 3(a) Temperature distribution for various value of K at $\gamma = 1$ and $Pr = 0.05$

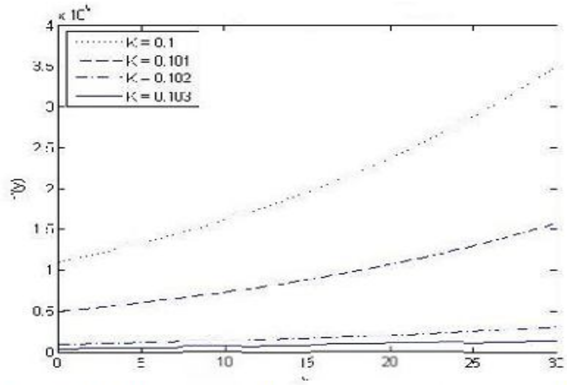

Fig. 3(b) Velocity distribution for various value of K at $\gamma = 1$ and $Pr = 0.05$

CONCLUSION

1. The governing equations are developed from continuity, momentum, and energy conservation. Further, those equations are transformed into boundary layer equations and transformed into a nondimensional form. The resulting nonlinear system of partial differential equations are solved numerically using the finite difference method.

2. This research has revealed how the Prandtl number and viscosity variable affect the flow and heat transfer characteristics. The temperature and velocity distributions decrease when the value of Prandtl number, Pr increases. While for the variation of viscosity variable, velocity distributions decrease when the value of viscosity variable, K increases while the opposite behavior is observed for the temperature profile.

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