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VISCOELASTIC FLUID FLOW WITH THE PRESENCE OF MAGNETIC FIELD PAST A POROUS CIRCULAR CYLINDER

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Abstract- We consider a magnetohydrodynamics (MHD) problem, i.e. Boundary layer flow of steady incompressible and viscoelastic fluid with the presence of magnetic field passing over porous circular cylinder. The effect of magnetic field that acts on the fluid is applied and assumed to be flowing in a porous medium. Dimensional Governing Equations are formulated from the physical phenomena and reduced by using boundary layer theory. These dimensional boundary layer further are converted into non-dimensional form by substituting several non-dimensional variables. Further, those nondimensional equations are transformed into similar equations and solved numerically by using finite difference method. The effect of various parameters involved in the solution have been studied. Numerical results for the flow quantities show that temperature profiles increase when both of viscoelastic parameter and mixed convective parameter increase.

Keywords- magnetohydrodynamics, boundary layer flow, viscoelastic fluid, porous medium

I. INTRODUCTION

Based on their characteristics, the fluid is divided into two types, i.e. Newtonian fluid and non-Newtonian fluid. Newtonian fluid is a fluid which has the viscous stresses arising from its flow, at every point, are linearly proportional to the local strain state. The Newtonian fluid isthe simplest mathematical model of fluid that accounts for viscosity. While no real fluids fits the definition perfectly, many common liquids and gases, can be assumed to be Newtonian for practical calculations under ordinary conditions [1] and [2]. However, non-Newtonian fluid is a fluid with properties that differ in any way from Newtonian fluids. The viscosity of non- Newtonian fluid is dependent on shear rate or shear rate history. The relation between shear stress and shear rate is different and can even be time-dependent. One example type of non-Newtonian fluid is viscoelastic fluid. Viscoelastic fluid is a fluid which has characteristics both of viscous and elastic. Because of its special characteristics, many researchers conduct their research to observe this fluid [3-12]. In this paper, we assume convective of heat transfer that happened on the fluid is mixed convection flow. The convective of heat transfer is a heat transfer from one place to another through the intermediary of a fluid caused by temperature difference. Mixed convection flow is a combination of free convection flow (natural) and force convection flow. In addition, mixed convection flow occurs when the effect of forces flow in free convection becomes significant. Boundary layer is a narrow region of a thin layer adjacent to the surface of an object when a real fluid flows past the body. The concept of boundary layer flow plays an important role in engineering automobile, and marine engineering [13]. Due to its importance in many engineering applications, the mixed convection boundary layer flow of non-Newtonian fluid in the presence of magnetic field have been attracted many researchers to investigate it[5-8]. These studies are also used for mathematical modeling and simulation. Ghosh and Shit [5] solved numerically boundary layer flow of viscoelastic fluid flow with short memory (obeying Walters' B fluid Model) passing over a hot vertical porous plate with the presence of magnetic field. The result of those show that Prandtl number has more pronouncing effect on the temperature distribution rather than the viscosity parameter, as well as the thermal radiation parameter. Research about boundary layer flow past stretching plate also have been investigated by other researchers [3] and [5-8]. Another geometric bluff bodies that have been observed for example are cylinder [4] and sphere [10]. Kasim [5] observes the boundary layer flow in some geometric bluff bodies, i.e. stretching plate, 2 cylinder, and sphere using Keller Box method for solving the problem. In order to study the mixed convection boundary layer flow of non-Newtonian fluid in the presence of magnetic field, we consider steady incompressible viscoelastic fluids past a porous circular cylinder. The geometry illustration and the coordinate system for the problem are depicted in the Fig. 1. For the problem, the uniform velocity of ambient fluid is $\frac{1}{2}U_\infty$, temperature on the surface of the cylinder is T_w , and temperature of ambient fluid is T_∞. We assume that the problem occurred on infinite domain.

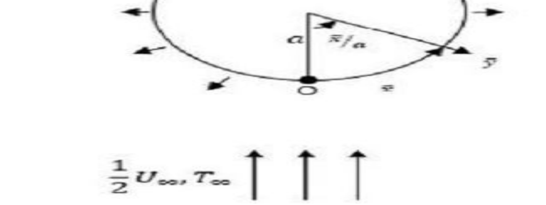

Fig. 1. Physical model and coordinate system

II. MATHEMATICALMODELLING AND SIMULATION

Considering the physical model and coordinate system on mixed convection flow of magnetohydrodynamics viscoelastic fluid that has been illustrated in Fig.1. We can formulate mathematical model of the problem.

A. Governing Equation Formulation

In this paper, the fluid induced magnetic field has a magnetic force B= $(0,0,B_o)$. The magnetic Reynold number is assumed to be small enough so that the induced magnetic field b (where$B = B_o + b$) can be neglected. In these assumption, the magnetic force J× Bbecomes $\sigma(V \times B) \times B = -\sigma B_0^2 V$1]

Consequently, we here introduce dimensional Governing Equations (GE) of the problem that have been formulated by using Conservation Law, under assumption that has been mentioned before and the boundary layer approximation [14]. Continuity, momentum, and energy equation of the system can be written:

Continuity Equation:

$$\frac{\partial \bar{u}}{\partial \bar{x}} + \frac{\partial \bar{v}}{\partial \bar{y}} = 0 \tag{1}$$

Momentum Equation:

$$\bar{u}\frac{\partial \bar{u}}{\partial \bar{x}} + \bar{v}\frac{\partial \bar{u}}{\partial \bar{y}} = \bar{u}_e\frac{\partial \bar{u}_e}{d\bar{x}} + \nu\frac{\partial^2 \bar{u}}{\partial \bar{y}^2} - \left(\frac{1}{\rho}\sigma B_0^2 + \frac{\nu}{\kappa}\right)(\bar{u} - \bar{u}_e) + g\,\beta(T - T_\infty)\sin\left(\frac{x}{a}\right) - \frac{k_0}{\rho}\left[\bar{u}\left(\frac{\partial^3 \bar{u}}{\partial \bar{x}\partial \bar{y}^2}\right) + \bar{v}\frac{\partial^3 \bar{u}}{\partial \bar{y}^3} - \frac{\partial \bar{u}}{\partial \bar{y}}\left(\frac{\partial^2 \bar{u}}{\partial \bar{y}\,\partial \bar{x}}\right) + \frac{\partial \bar{u}}{\partial \bar{x}}\left(\frac{\partial^2 \bar{u}}{\partial \bar{y}^2}\right)\right] \tag{2}$$

Nomenclature

V	Velocity component of fluid
u	Velocity component in x-direction
v	Velocity component in y-direction
u_e	Velocity outside the boundary layer region
g	Gravitational field
J	Current density
B	Magnetic force
B_0	Magnetic field
b	Induced magnetic field
a	Radius of the cylinder
K	Viscoelastic parameter
M	Magnetic parameter
k_0	Short-memory coefficient
Pr	Prandtl number
Re	Reynolds number
Gr	Grashof number
x	Coordinate in direction of surface motion
y	Coordinate in direction normal to surface motion
Greek symbols	
ρ	Fluid density
ν	Kinematic viscosity
α	Thermal diffusivity
β	
μ_0	Dynamic viscosity
ϕ	Porosity parameter
σ	Electrical conductivity
κ	Permeability of porous medium
λ	Mixed confection parameter
θ	Non-dimensional temperature
ψ	Stream function
Superscripts	
'	Differentiation with respect to y

Energy Equation:

$$\left(\bar{u}\frac{\partial T}{\partial \bar{x}} + \bar{v}\frac{\partial T}{\partial \bar{y}}\right) = \alpha\frac{\partial^2 T}{\partial \bar{y}^2} \tag{3}$$

Subjected to Boundary Condition:

$$\bar{u} = \bar{v} = 0,\ T = T_w, \text{ at } \bar{y} = 0,$$

$$\bar{u} = \bar{u}_e, \frac{\partial \bar{u}}{\partial \bar{y}} = 0, T = T_\infty, \text{ when } y \to \infty. \tag{4}$$

where T_w is constant cylinder wall temperature.

These dimensional boundary layer equation are transformed into non-dimensional governing equation by substituting non-dimensional variables. The nondimensional variables as follows:

$$x = \frac{\bar{x}}{a}, y = Re^{\frac{1}{2}}\left(\frac{\bar{y}}{a}\right), u = \frac{\bar{u}}{U_\infty},$$

$$v = Re^{\frac{1}{2}}\left(\frac{\bar{v}}{U_\infty}\right), u_e = \frac{\bar{u}_e(\bar{x})}{U\_\infty}. \theta = \frac{(T - T_\infty)}{(T_w - T_\infty)} \tag{5}$$

where $Re = \frac{U_\infty a}{\nu}$. By substituting Equation (5) into dimensional governing equations (1), (2), and (3), we obtain the non-dimensional equations i.e.:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{6}$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = u_e\frac{du_e}{dx} + \frac{\partial^2 u}{\partial y^2} - (M + \phi)(u - u_e) + \lambda\theta\sin x - K\left[\frac{\partial}{\partial x}\left(u\frac{\partial^2 u}{\partial y^2}\right) + v\frac{\partial^3 u}{\partial y^3} + \frac{\partial u}{\partial y}\frac{\partial^2 v}{\partial y^2}\right] \tag{7}$$

$$u\frac{\partial \theta}{\partial x} + v\frac{\partial \theta}{\partial y} = \frac{1}{Pr}\frac{\partial^2 \theta}{\partial y^2} \tag{8}$$

The Boundary Conditions (4) becomes:

$$u = v = 0, \theta = 1, \text{ at } y = 0,$$

$$u = u_e(x), \frac{\partial u}{\partial y} = 0, \theta = 0, \text{ when } y \to \infty. \tag{9}$$

where $K, M, \phi, \lambda,$ and Pr are dimensionless parameter.Those parameters are defined as follows:

$K = \frac{(k_0 U_\infty)}{(a\rho\nu)}$	(Viscoelastic Parameter)
$M = \frac{\sigma B_0^2 a}{\rho U\_\infty}$	(Magnetic Parameter)
$\phi = \frac{\nu a}{\kappa U_\infty}$	(Porosity Parameter)
$\lambda = \frac{Gr}{Re^2}$	(Mixed Convection Parameter)
$Gr = \frac{g\beta(T_w - T_\infty)a^3}{\nu^2}$	(Grashof Number)
$Pr = \frac{\nu}{\alpha}$	(Prandtl Number)

B. Solution Procedure

Let us introduce the similarity variable to solve the set of non-dimensional governing equations (6) to (8) and boundary conditions (9):

$$\psi = xf(x, y)$$

$$\theta = \theta(x, y) \tag{10}$$

Where ψ is stream function which is defined as follows:

$$u = \frac{\partial \psi}{\partial y} \text{and} v = \frac{\partial \psi}{\partial x} \tag{11}$$

With the use of above variables into Equation (6) to (8) and substitute $u_e = \sin x$ [15], we obtain:

Momentum equation:

$$\frac{\partial^3 f}{\partial y^3} + f\frac{\partial^2 f}{\partial y^2} - \left(\frac{\partial f}{\partial y}\right)^2 + \frac{\sin x\cos x}{x} - (M + \phi)\left(\frac{\partial f}{\partial y} - \frac{\sin x}{x}\right) + \lambda\frac{\sin x}{x}\theta - K\left(2\frac{\partial f}{\partial y}\frac{\partial^3 f}{\partial y^3} - f\frac{\partial^4 f}{\partial y^4} - \left(\frac{\partial^2 f}{\partial y}\right)^2\right) - Kx\left(\frac{\partial^2 f}{\partial x\partial y}\frac{\partial^3 f}{\partial y^3} - \frac{\partial f}{\partial x}\frac{\partial^4 f}{\partial y^4} + \frac{\partial f}{\partial y}\frac{\partial^4 f}{\partial x\partial y^3} - \frac{\partial^2 f}{\partial y^2}\frac{\partial^3 f}{\partial x\partial y^2}\right) = x\left(\frac{\partial f}{\partial y}\frac{\partial^2 f}{\partial x\partial y} - \frac{\partial f}{\partial x}\frac{\partial^2 f}{\partial y^2}\right) \tag{12}$$

Energy equation:

$$\frac{1}{Pr}\frac{\partial^2 \theta}{\partial y^2} + f\frac{\partial \theta}{\partial y} = x\left(\frac{\partial f}{\partial y}\frac{\partial \theta}{\partial x} - \frac{\partial f}{\partial x}\frac{\partial \theta}{\partial y}\right) \tag{13}$$

and the Boundary Conditions (9) becomes:

$$f = \frac{\partial f}{\partial y} = 0, \theta = 1 \qquad \text{at } y = 0,$$

$$\frac{\partial f}{\partial y} = \frac{\sin x}{x}, \frac{\partial^2 f}{\partial y^2} = 0, \theta = 0 \qquad \text{while } y \to \infty. \qquad (14)$$

At the lower stagnation point ($x \approx 0$), both Equations (12) and (13) are reduced into highly non-linier ordinary differential equations

$$f''' + f f'' - f'^2 + 1 - (M + \phi)(f' - 1) + \lambda\theta - K(2 f' f''' - f f^{(4)} - f''^2) = 0 \qquad (15)$$

$$\frac{1}{Pr}\theta'' + f\,\theta' = 0 \qquad (16)$$

Subjected to Boundary Conditions:

$$f(0) = f'(0) = 0, \theta(0) = 1,$$

$$f'(\infty) = 1, f''(\infty) = 0, \theta(\infty) = 0. \qquad (17)$$

C. Numerical Solution

The set of Similar Equations (15) and (16) and Boundary Condition (17) is solved by finite difference
method. These ordinary differential equations are discretized by a second order central difference scheme
and solved by a computer program which has been developed.

III. RESULT AND DISCUSSION

In this study, the mixed convective boundary layer flow on non-Newtonian fluid in the presence of magnetic field past a porous circular cylinder is investigated numerically using FDM scheme. The fluid is viscoelastic fluid, which has characteristics both of viscous and elastic, with the presence of magnetic field. The objective of the present analysis is to study the temperature profiles and velocity profiles of viscoelastic fluid flow with the variation of viscoelastic parameter (K) and mixed convection parameter (γ). The variation on velocity profile and temperature profile at various value of viscoelastic parameter

areillustrated in Fig. 2 and Fig. 3 respectively. These numerical results have been made at fixed values of $M = 0.5$, $\phi = 0.1, \lambda = Pr = 1$. The results show that velocity profiles in Fig. 2decrease when viscoelastic parameter increase. It caused by friction force in viscoelastic fluid getting bigger when the viscoelastic parameter increase. The temperature profilesin Fig. 3 increase when viscoelastic parameter increase. From those results, we can assume that fluid moves slower when the fluid has high viscosity and elasticity than the low ones. The influence of mixed convection parameter on the velocity profiles and temperature profiles can be seen in Fig. 4 and Fig.5 respectively. These numerical results have been made at fixed values of $M = 0.5, \phi = 0.1, K = 1,$ and $Pr = 1$. The velocity profiles in **Fig. 4** decrease when mixed convection parameter increase, however, the temperature profiles in **Fig. 5** increase when mixed convection parameter increase. From **Fig. 5** we can conclude that the temperature distribution increases when cylinder is heated ($\lambda > 0$).

Fig. 6 shows the effect of increasing Prandtl number on temperature profiles of the flow. These numerical results have been made at fixed values of $M = 10$, $\lambda = 2$, $K = 10$, $\phi = 0.1$. The result shows that temperature profiles decrease when Prandtl number increase. This is expected because the increasing of Prandtl number will affect the kinematic viscosity and thermal diffusivity of the fluid.

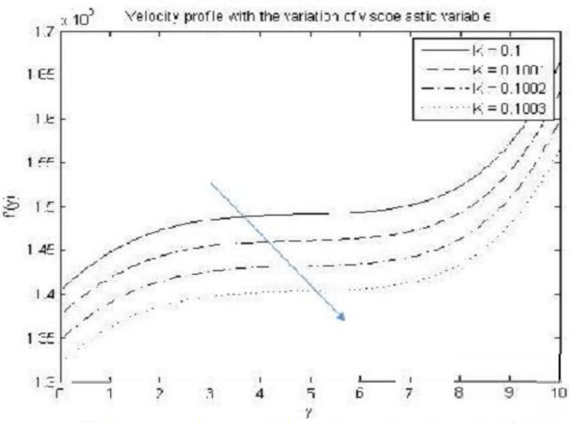

Fig. 2. Velocity profiles with fixed $M = 0.5, Pr = 1, \phi = 0.1, \lambda = 1$ and variation of viscoelastic parameter (K)

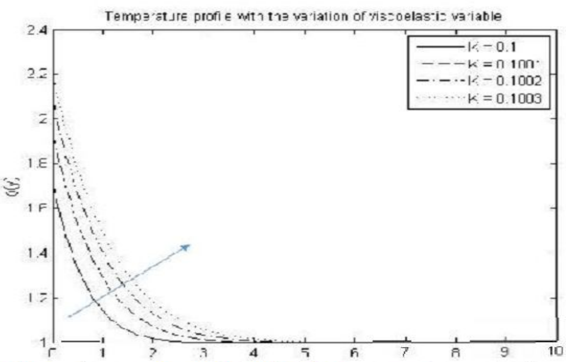

Fig. 3. Temperature profiles with fixed $M = 0.5, Pr = 1, \phi = 0.1, \lambda = 1$ and variation of viscoelastic parameter (K)

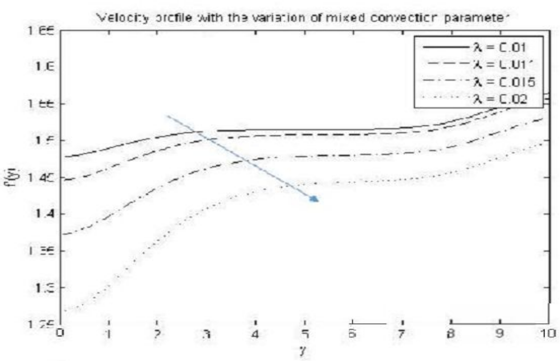

Fig. 4. Velocity profiles with fixed $M = 0.5$, $Pr = 1, K = 1, \phi = 0.1$ and variation of mixed convection parameter (λ)

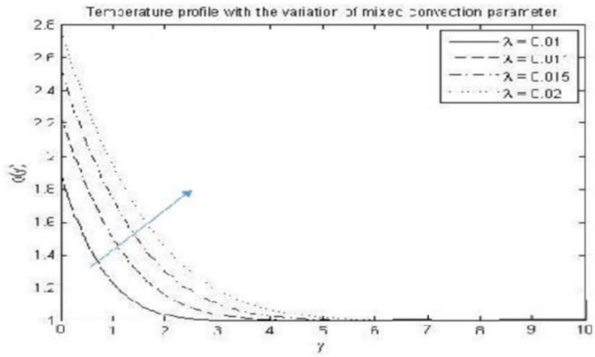

Fig. 5. Temperature profiles with fixed $M = 0.5$, $Pr = 1$, $K = 1$, $\phi = 0.1$ and variation of mixed convection parameter (λ)

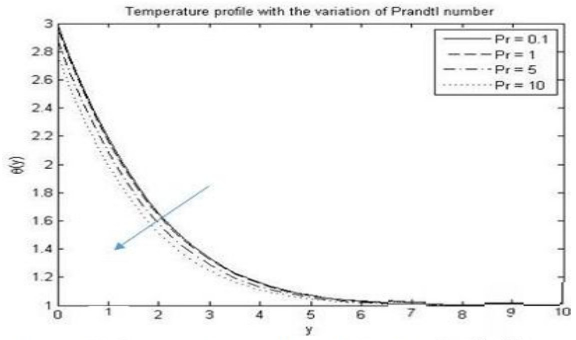

Fig. 6. Temperature profiles with fixed $M = 10$, $\lambda = 2$, $K = 10$, $\phi = 0.1$ and variation of Prandtl number (Pr)

CONCLUSIONS

Viscoelastic fluid flow with the presence of magnetic field past a porous circular cylinder is investigated numerically by using finite difference method. The effects of the viscoelastic parameter, mixed convection parameter, and Prandtl number on the flow characteristic have been examined. The results show that as both of viscoelastic parameter and mixed convection parameter increase then the velocity profile of the flow decrease. However, temperature profiles increase when both viscoelastic parameter and mixed convection parameter increase. The influence of Prandtl number shows that temperature profiles decrease when Prandtl number increases.

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