

Dufour Effects on Unstable MHD Viscoelastic Fluid Flow in Porous Vertical Media Current Pressure Gradient

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Abstract

This specific investigation analyses Dufour effect in the context of free flow within vertical porous media and unstable MHD (Magnetohydrodynamics). We explore various effects, including Dufour, radiation, and radiation chemical reactions. We convert the flow equations into differential equations using specific parameters and employ the perturbation method with sliding boundary conditions to solve the problem. We investigate differential parameters for the temperature, velocity and concentration distributions, including Grashoff numbers of mass and temperature transfer, as well as the Schmidt number. Additionally, we demonstrate how to analyse the problem using MATLAB. Further research is needed to delve into the effects of the Soret effect.

Keywords: MHD; invasion of the media; heat sources; antidote; occupy media; Dufour.

1. Introduction

The research focuses on unstable materials in the presence of vertical perforated plates, considering various factors such as thermal explosions, chemical reactions, continuous absorption, and MHD effects. Changes in unstable materials M.L. Ramamohan Reddy vertical perforated plates [1]. In the light of thermal explosion, continuous absorption and chemical reactions, M.C. Raju [3] studied MHD free convection and diffusion boundary layered flow on a permeable vertical surface. Mohanty studied the MHD flow of the viscoelastic fluid through heterogeneous permeable media along with heat source and oscillating suction [4].

Deka [5] found thermal diffraction in a vertically oscillating plate and also turbulent MHD flow different from mass distribution. The unstable MHD double diffusion convective boundary layer passes vertically through the chemical material and dissipates heat. R. A. Mohamed studied radiators [6]. R. Kandasamy [7] investigated the effect of chemical, electricity generation and air movement, and temperature in the light of suction or injection. M. Umamaheswar [8] investigates MHD free convection viscoelastic fluid flow confined by infinitely fine curved perforated plate in a thermal source viscous dispersion, and Joule heating.

Murali Gundagani described unstable magnetohydrodynamic free convection along a perforated vertical plate [9]. J. I. Oahimire [10] studied the magnetic flux at the stagnation point of starch with different thermal conductivities and heat sinks. S. Sreenadh [11] studied the effect of cutting and transferring electricity by placing Williamson fluid in an inclined column using peristalsis. B.

Mamatha examined the micro-polar fluid through partial absorption cracks in an unstable MHD mixed convective radiative boundary layer [12].

K.V.S. Raj found that free heat and air exchange in a vertical grid is very fast with Newtonian heat [13]. Hot substances such as gas sometimes ionize and are highly charged. Magnetic fields interact with the ionized plasma or liquid, causing changes in heat and friction. Since some liquids can do two jobs, it is interesting to see how the magnetic field is affected by temperature changes when the liquid is an electric current, current, and emitter. Since, the chemical industry increases the reaction rate, more care must be taken when controlling the heat and air changes in the chemical process. V. Rajesh [14] examined the effect of thermal source along with surface quality on the elastoviscous MHD flow in perforated plate. S.F. Ahmed studied the impact of unstable MHD natural convection on mass transfer in perforated plate that is vertical [15]. Mondal [16] studied the electrical and chemical properties of MHD free convection through plates of vertical porous material. Mangali Veerakrishna [17] studied thermal and mass transport of secondary fluid into a weak magnetohydrodynamic oscillating flow between two plates that are vertical with constant change in instruments/sinks and chemicals. Furhad Ali [18] studied heat, air transfer from a freely flowing MHD fluid on a vertical plate to a permeable medium. Misra [19] captured motion of a Biomagnetic viscoelastic fluid on an extended plate. K. Das [20] studied convection without MHD near a moving plate in the visual of thermal radiation.

This study, based on this research. Instead of focusing on Newtonian fluids, we study unstable MHD viscoelastic fluid flow in a vertical medium along with pressure gradients. This study is unique in that it explores how the viscoelastic fluid relates to Dufour and the time-dependent fluctuation absorption of the medium in the presence of electrochemistry.

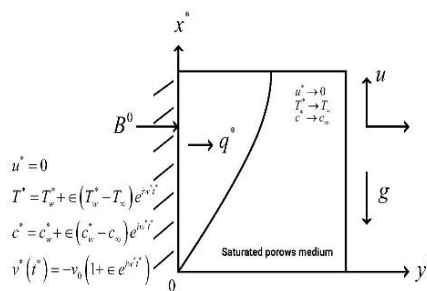
2. Design of the Problem

The design problem revolves around the time-dependent oscillating absorption and permeability of infinite vertical permeable plate, immersed in endothermic viscoelastic fluid. This fluid is subject to electric reactions, electric suction along with a change in magnetic-field, while Y^* axis remains normal for the X^* axis, representing flow direction. The magnetic Reynolds number is considered minimum, and induced magnetic fields are disregarded. Buoyancy forces due to temperature imbalance between the wall and the middle section are the main cause of disturbances in the middle part. The study accounts for Dufour's influence and examines how the plate's temperature changes with time, from $t^*=0$, when the plate and the fluid are at the identical temperature, to t^* , when the plate's temperature reaches TW^* , and the mode transitions to CW^* .

The permeability and absorption rate of porous media are represented by the following equations:

$$K^*(t^*) = K^* p (1 + e^{iw^* t^*}) \quad (1)$$

$$v^*(y^*) = (1 + e^{aw^* t^*}).$$



Flow Geometry

Applying the previously indicated assumption and normal Boussinesq's approximation, governing equations and boundary conditions are provided as follows: where $t > 0$ and 1 are said to be positive constants.

$$\frac{\partial u^*}{\partial t^*} = \vartheta \frac{\partial^2 y^*}{\partial y^{*2}} + g\beta(T^* - T_\infty^*) + g\beta^*(c^* - c_\infty^*) - \sigma\beta_0^2 \frac{u^*}{\rho} - \vartheta \frac{u^*}{k^*} - \frac{k_0}{\rho} \left(\frac{\partial^3 u^*}{\partial t^* \partial y^{*2}} + v^2 \frac{\partial^3 u^*}{\partial y^{*2}} \right) \quad (2)$$

$$\frac{\partial T^*}{\partial t^*} \rho c_p = k \frac{\partial^2 T^*}{\partial y^{*2}} - \frac{\partial q^*}{\partial y^2} - Q^*(T^* - T_\infty^*) + Q_1^*(c^* - c_\infty^*) \quad (3)$$

$$\frac{\partial c^*}{\partial t^*} = D \frac{\partial^2 c^*}{\partial y^{*2}} - k_r(c^* - c_\infty^*) + \frac{Dk_T}{T_m} \frac{\partial^2 T}{\partial y^2} \quad (4)$$

$$u = 0, T^* = T_w + \varepsilon(T_w - T_\infty)e^{iw^*t^*},$$

$$C^* - C_w + \varepsilon(C_w - C_\infty)e^{iw^*t^*} \text{ at } y = 0 \quad (5)$$

$$u \rightarrow 0, T^* \rightarrow T_\infty, C^* \rightarrow C_\infty \text{ as } y \rightarrow \infty$$

Introduce non-dimensional equations

$$y = \frac{v_0 t^*}{\vartheta}, t = \frac{v t^*}{4\vartheta}, w = \frac{4\gamma w^*}{v_0^2}, u = \frac{u^*}{v_0},$$

$$T = \frac{T^* - T_\infty^*}{T_w - T_\infty}, C = \frac{C^* - C_\infty^*}{C_w - C_\infty}, s = \frac{\vartheta s^*}{v_0^2}, K_p = \frac{v_0^2 k_p^2}{\vartheta^2}, m^2 = \sigma \frac{B_0^2 \vartheta}{v_0^2 \rho}, P_r = \frac{\vartheta}{k'}, s_c = \frac{\vartheta}{D}, R_c = \frac{v_0^2 k_0}{\vartheta^2 \rho},$$

$$G_c = \frac{v g \beta^* (c_w - c_\infty)}{v_0^3}, G_r = \frac{v g \beta (T_w - T_\infty)}{v_0^3},$$

$$F = \frac{4I_1 \vartheta}{v_0^2 \rho c_p}, S = \frac{Q \vartheta}{v_0^2 \rho c_p}, k_c = \frac{kr \vartheta}{v_0^2}$$

$$R = \frac{Q_1 \vartheta (c_w - c_\infty)}{v_0^2 \rho (T_w - T_\infty)}, S_r = \frac{Dk_T}{T_m} \left(\frac{T_w - T_\infty}{c_w - c_\infty} \right) \quad (6)$$

Equation (3), (4), (5) reduces to a non-dimensional form

$$\frac{1}{4} \frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} + G_r T + G_c C - \left(m^2 + \frac{1}{k_p} \right) u - \frac{1}{4} R_c \left\{ \frac{\partial^3 u}{\partial t \partial y^2} - 4(1 + \varepsilon e^{iwt}) \frac{\partial^3 u}{\partial y^3} \right\} \quad (7)$$

$$\frac{1}{4} \frac{\partial T}{\partial t} = \frac{1}{P_r} \frac{\partial^2 T}{\partial y^2} - HT + R_c \quad (8)$$

$$\frac{1}{4} \frac{\partial C}{\partial t} = \frac{1}{s_c} \frac{\partial^2 C}{\partial y^2} - k_r C + S_r \frac{\partial^2 T}{\partial y^2} \quad (9)$$

$$u = 0, T = 1 + \varepsilon e^{i\omega t}, c = 1 + \varepsilon e^{i\omega t} \text{ at } y = 0 \quad (10)$$

$$u \rightarrow 0, T \rightarrow 0, C \rightarrow 0 \text{ as } y \rightarrow \infty$$

3. Method of Solution

Let us assume the concentration (C), velocity (u) and temperature (T) to be as follows,

$$\left. \begin{aligned} u(y, t) &= u_o(y) + \varepsilon u_1(y) e^{i\omega t} \\ T(y, t) &= T_o(y) + \varepsilon T_1(y) e^{i\omega t} \\ C(y, t) &= C_o(y) + \varepsilon C_1(y) e^{i\omega t} \end{aligned} \right\} \quad (11)$$

Misra and Shit [19] and Das and Das [20] use the approach described above to solve a regularly varying flow problem. After substituting (11), we get the harmonic in non-harmonic terms of (7), (8), and (9)

$$R_c u_o''' + u_o'' - \left(m^2 + \frac{1}{k_p}\right) u_o = -G_r T_o G_c C_o \quad (12)$$

$$R_c u_1''' + u_1'' \left(1 - \frac{R_c i\omega}{4}\right) - \left(m^2 + \frac{1}{k_p} + \frac{i\omega}{4}\right) u_1 = -G_c C_1 - G_r T_1 - R_c u_o''' \quad (13)$$

$$T_o'' - P_r H T_o = -R P_r C_o \quad (14)$$

$$T_1'' - \left(H + \frac{i\omega}{4}\right) P_r T_1 = -R P_r C_1 \quad (15)$$

$$C_o'' - k_c s_c c_o = -s_r s_c (1 + R_c) B_7 v_1^2 e^{v_1 y} \quad (16)$$

$$C_1'' - \left(k_c + \frac{i\omega}{4}\right) s_c c_1 = -s_c s_r (1 + R_c) B_8 v_2^2 e^{v_2 y} \quad (17)$$

$$u_0 = u_1 = 0, T_0 = T_1 = 1, c_0 = c_1 = 1 \text{ at } y = 0$$

$$u_0 = u_1 \rightarrow 0, T_0 = T_1 \rightarrow 1, c_0 = c_1 \rightarrow 1 \text{ at } y \rightarrow \infty \quad (18)$$

Equations (12) and (13) are third order, but still, we get two boundary conditions. Therefore, our perturbation method for the R_c (Elastic Parameter) is,

$$\left. \begin{aligned} u_0 &= u_{00}(y) + R_c u_{01}(y) + 0(R_c^2) \\ u_1 &= u_{10}(y) + R_c u_{11}(y) + 0(R_c^2) \end{aligned} \right\} \quad (19)$$

Substituting (19) in (12) and (13) and equating R_c^2 and R_c Co-efficient

We get other following ordinary differential equations

Zeroth Order Equations

$$u_{00}'' - \left(m^2 + \frac{1}{k_p}\right) u_{00} = -G_c c_0 - G_r T_0 \quad (20)$$

$$u_{01}'' - \left(m^2 + \frac{1}{k_p}\right) u_{01} = -u_{00}''' \quad (21)$$

First Order Equations

$$u''_{10} - \left(m^2 + \frac{1}{k_p} + \frac{iw}{4}\right)u_{10} = -G_c C_1 - G_r T_1 \tag{22}$$

$$u''_{11} - \left(m^2 + \frac{1}{k_p} + \frac{iw}{4}\right)u_{11} = -u'''_{00} - u'''_{10} + \frac{iw}{4}u''_{10} \tag{23}$$

Applying boundary conditions for equations (14) and (15) with the regular perturbation method, we get

$$\left. \begin{aligned} T_0 &= T_{00}(y) + R_c T_{01}(y) \\ T_1 &= T_{10}(y) + R_c T_{11}(y) \end{aligned} \right\} \tag{24}$$

Substituting (24) in (14) and (15) and equating R_c and constants. We obtain the following ordinary differential equations

Zeroth Order Equations

$$T''_{00} - P_r H T_{00} = -R P_r C_0 \tag{25}$$

$$T''_{01} - P_r H T_{01} = 0 \tag{26}$$

First order Equations

$$T''_{10} - \left(H + \frac{iw}{4}\right)P_r T_{10} = -R P_r C_1 \tag{27}$$

$$T''_{11} - \left(H + \frac{iw}{4}\right)P_r T_{11} = 0 \tag{28}$$

Applying boundary conditions for equations (16) and (17) with the regular perturbation method

We get

$$\left. \begin{aligned} C_0 &= C_{00}(y) + R_c C_{01}(y) \\ C_1 &= C_{10}(y) + R_c C_{11}(y) \end{aligned} \right\} \tag{29}$$

Substituting (29) in (16) and (17) and equating R_c and constants

Zeroth Order Equations

$$C''_{00} - k_c s_c C_{00} = -s_r s_c B_7 \ell_1^2 e^{\ell_1 y} \tag{30}$$

$$C''_{01} - k_c s_c C_{01} = -s_r s_c B_7 \ell_1^2 e^{\ell_1 y} \tag{31}$$

First order Equations

$$C''_{10} - \left(s_c k_c + s_c \frac{iw}{4}\right)C_{10} = -s_c s_r B_8 \ell_2^2 e^{\ell_2 y} \tag{32}$$

$$C''_{11} - s_c k_c c_{11}(y) - s_c \frac{iw}{4}C_{11} = -s_c s_r B_8 \ell_2^2 e^{\ell_2 y} \tag{33}$$

The corresponding boundary conditions are,

$$u_{00} = u_{01} \rightarrow 0, u_{10} = u_{11} \rightarrow 0, T_{00} = T_{01} \rightarrow 0, T_{10} = T_{11} \rightarrow 0, C_{00} = C_{01} \rightarrow 0, C_{10} = C_{11} \rightarrow 0$$

as $y = 0$ and

$$u_{00} = u_{01} \rightarrow 0, u_{10} = u_{11} \rightarrow 0, T_{00} = T_{01} \rightarrow 0, T_{10} = T_{11} \rightarrow 0, c_{00} = c_{01} \rightarrow 0, c_{10} = c_{11} \rightarrow 0$$

as $y = \infty$ (34)

Solving the above differential equations with help of boundary conditions, we get

$$u(y, t) = B_2(e^{-\sqrt{a_1}y} - e^{\sqrt{a_1}y}) - (G_r T_0 + G_c c_0) \frac{y}{a_1} + R_c [B_1(e^{-\sqrt{a_1}y} - e^{\sqrt{a_1}y} - a_1^2 e^{a_1 y} y)] + \varepsilon e^{i\omega t} \left[B_3(e^{-\sqrt{a_2}y} - e^{\sqrt{a_2}y}) - (G_r T_1 + G_c c_0) \frac{y}{a_2} + R_c (B_4(e^{-\sqrt{a_2}y} - e^{\sqrt{a_2}y}) - B_1 a_1^2 e^{a_1 y} y - B_2 a_2^2 e^{a_2 y} y + \frac{i\omega}{4} B_2 a_2 e^{a_2 y} y) \right] \quad (35)$$

$$T(y, t) = B_5(e^{-\sqrt{b_1}y} - e^{\sqrt{b_1}y}) - \frac{RPr}{\gamma_1} c_0 y + \varepsilon e^{i\omega t} (B_8(e^{-\sqrt{b_1}y} - e^{\sqrt{b_1}y})) \quad (36)$$

$$C(y, t) = B_{11}(e^{k_c s_c y} - 1) - s_r s_c B_7 \ell_1 e^{\ell_1 y} y + \varepsilon e^{i\omega t} \left[B_{10} \left(e^{(k_c + \frac{i\omega}{4}) s_c y} - 1 \right) - s_r s_c B_8 \gamma_2^2 e^{\gamma_2 y} y \right] \quad (37)$$

4. Result and Discussion

The work provides a series of findings related to various parameters and their impact on the velocity, temperature, concentration, and other factors in the studied system. Here's an enhanced explanation of each set of findings.

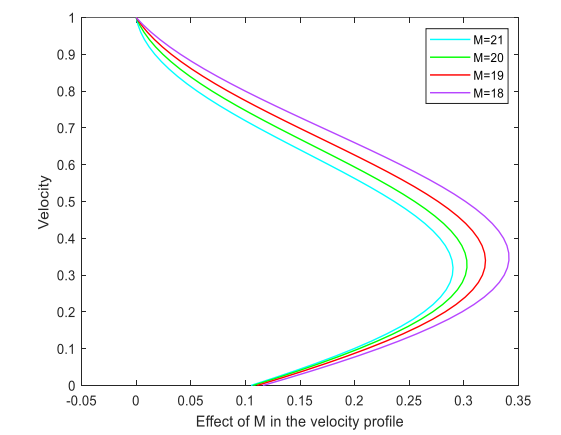


Figure 1

Magnetic Parameters:

Several magnetic parameters, namely Grashof number and modified Grashof number, were examined. The results of these investigations are presented in multiple tables.

Magnetic Field Influence on Velocity:

The figure above illustrates how the velocity profile changes concerning different magnetic field strengths, represented by M values ranging from 18 to 21. The velocity distribution displays variations based on the magnetic load (M). As M increases, the velocity decreases. This phenomenon occurs because the Lorentz force acts as a hindrance when a magnetic field is introduced into the system.

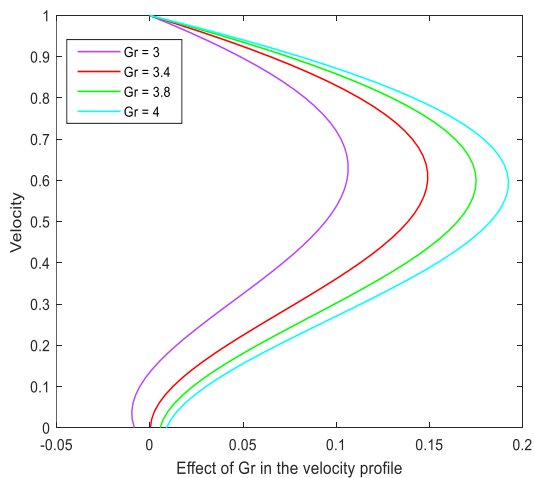


Figure 2

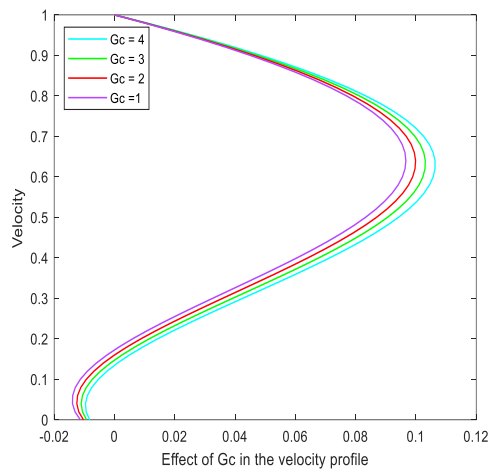


Figure 3

Buoyancy and Velocity Distribution:

The two graphs above depict the differences in velocity distribution associated with varying Grashof numbers (Gr) and modified Grashof numbers (Gc). Due to significant buoyancy forces, the water velocity increases, and evidently speed increases with rising values of Gr and Gc .

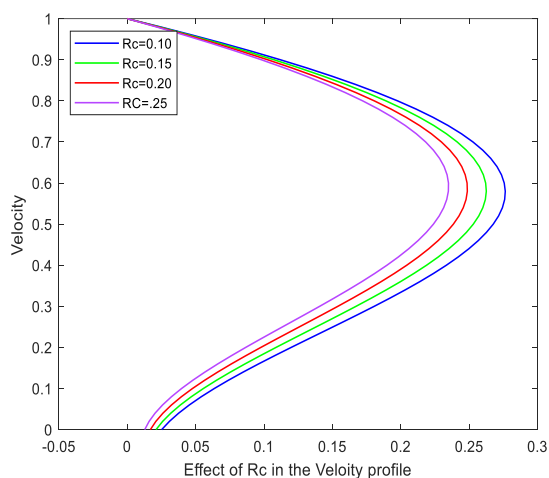


Figure 4

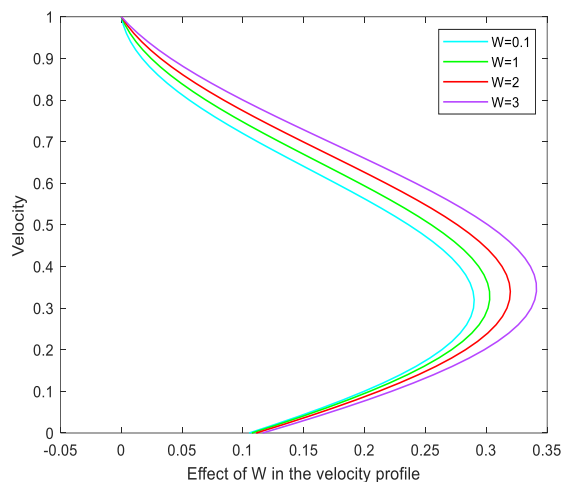


Figure 5

Viscoelastic Parameter Effect:

The figure above illustrates the relationship between viscoelastic parameters (R_c), with values ranging from 0.10 to 0.25. It has been shown that speed decreases when the viscoelastic parameter (R_c) rises.

Oscillation Frequency Impact on Velocity:

The figure above showcases the variation in velocity distribution concerning different oscillation frequencies (W) with values of 0.1, 1, 2, and 3. The effect of oscillation frequency (W) on velocity becomes more pronounced as W increases.

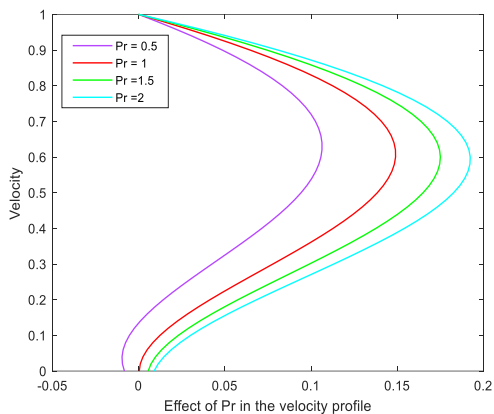


Figure 6

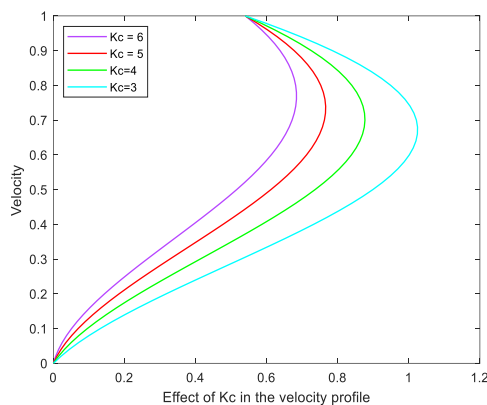


Figure 7

Prandtl Number Influence:

The relationship between velocity profile and the Prandtl number (Pr) is displayed above, with Pr values ranging from 0.5 to 2. A rapid increase in Prandtl number is associated when the fluid's velocity drops. This is attributed to the reduction in thermal conductivity as the Prandtl number rises.

Chemical Concentration Distribution:

The diagram above depicts the distribution of chemical concentrations (Kc) with values of 3, 4, 5, and 6. Remarkably, there appears to be no significant effect on speed. However, the velocity of the particular flow does decrease with the increasing chemical resistance (Kc) for the given problem.

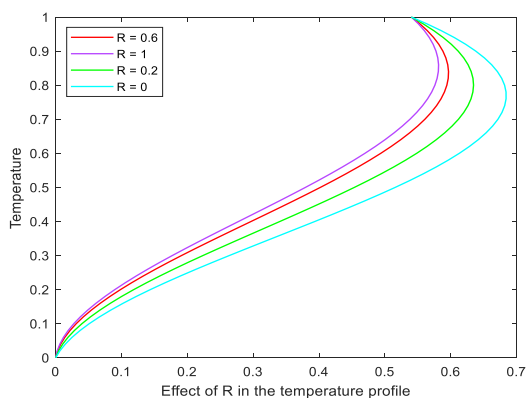


Figure 8

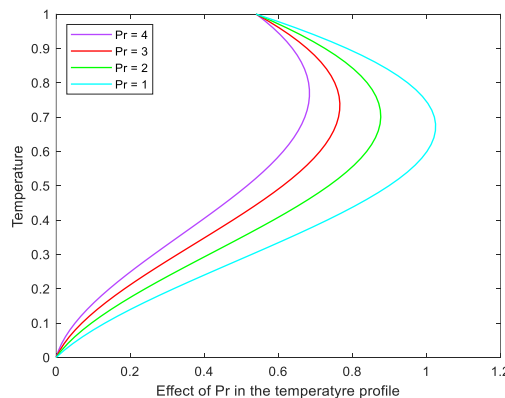


Figure 9

Electrical Absorption Effect:

The diagram above demonstrates the variation in temperature due to changes in the electrical absorption coefficient (R) with values of 0, 0.2, 0.6, and 1. There is a raise in the electrical absorption coefficient leads to a drop in temperature in the temperature profile.

Prandtl Number and Temperature:

The figure above presents the temperature at different Prandtl numbers (Pr) ranging from 1 to 4. As the Prandtl number raises, the influence on temperature drops for the respective flow pattern.

5. Conclusion

We investigated the dynamics of a viscoelastic fluid flow along a vertical porous plate that is unstable in Magnetohydrodynamics (MHD). Many contributing elements, such as a pressure gradient, a magnetic field, a permeable material with time-dependent oscillatory permeability and suction, and the Dufour effect, were taken into account when conducting this research. These are the main conclusions that need to be discussed:

(i) Enhancement of Concentration Profile by Dufour Effect:

One significant observation from our study is the impact of the Dufour effect. It is noteworthy that this effect has a somewhat enhancing influence on the concentration profile of the fluid. The Dufour effect is a heat-mass transfer phenomenon, and its presence in this system plays a role in shaping the concentration distribution of the fluid. This finding underscores the importance of considering heat-mass transfer effects in similar systems.

(ii) Magnetic Field Slows Fluid Flow:

The effect of a magnetic field on the flow dynamics was observed to be significant. It was noted that the magnetic field hinders the fluid, flow. The decrease in speed of the fluid is caused by the interaction between magnetic field and fluid's ability to conduct electricity. Gaining a comprehensive understanding of this impact is essential for optimizing procedures that need precise control or adjustment of fluid flow.

(iii) Reduction of Flow at Boundary Layer Due to Species Conductivity:

Another important finding pertains to the flow characteristics at boundary layer of the fluid. The study revealed that the flow at the boundary layer is reduced. This reduction can be attributed to the presence of heavier species in the fluid, which generally have lower conductivities. The relationship between species properties, conductivities, and flow behaviour at the boundary layer is a crucial insight, particularly in applications where species differentiation plays a vital role.

To summarize, our study of the flow of unstable magnetohydrodynamic viscoelastic fluid in a complicated system containing a vertical permeable plate, a pressure gradient, a magnetic field, a permeable medium with time-dependent permeability, and the Dufour effect has resulted in these significant discoveries. These findings enhance our comprehension of the intricate interactions between different elements in these systems, and have practical implications for domains including fluid dynamics, heat-mass transfer, and materials processing.

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