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Ohmic Heating Effect of Viscoelastic Dielectric Liquid over a Slanted Stretching Sheet

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Abstract: This research explores the Ohmic heating phenomenon in a dielectric liquid flowing over an inclined, stretching sheet. It also highlights the significance of the permeability parameter in heat transfer. The fundamental governing equations undergo a transformation into ordinary differential equations (ODEs) by applying a similarity transformation. This approach simplifies the problem by reducing the number of independent variables, making the equations more manageable for analytical or numerical solution. To obtain the numerical solution, the well-established Runge-Kutta-Fehlberg method combined with the shooting technique is employed. The study examines the impact of various key parameters on fluid flow and heat transfer, with results presented graphically. Additionally, numerical values of skin friction and the Nusselt number are provided in a table for different parameter variations.

Keywords: *Stretching Sheets, Viscoelastic, Inclined, Ohmic Effect.*

1. Introduction

Heat transfer and velocity analysis in porous media is essential in many engineering and sciences. The utilization of Ohmic heating with dielectric liquids in the fields of extraction and purification, Metallurgy and metal processing, fuels and energy production, showcases its potential to improve efficiency, precision, and control in various industrial processes, impacting mining, materials science, and fuel-related industries by enhancing heating methods and refining processes.This study has various applications in many systems, from biological tissues to composite materials, soil, wood, mines, and paper and also in fuels. Permeability is vital in designing and optimizing filtration system, enhancing fluid flow while efficiently capturing particulates or contaminants.

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2. Review of related literature

Numerous studies have investigated the impact of Ohmic heating and related mechanisms on fluid flow and heat transfer. For instance, research conducted by [1] focused on the effects of Ohmic heating and viscous dissipation on the steady flow of a viscous, incompressible, and electrically conducting fluid in the area of a stagnation point. This study specifically examined the interaction between a uniform transverse magnetic field and a variable free stream over a non-conducting, isothermal stretching sheet. In a similar context, the work presented in [2] explored the combined influence of Ohmic heating and chemical reactions on the behavior of a magnetohydrodynamic (MHD) micropolar fluid flowing past a stretching surface. This study emphasized the significance of chemical reactions in altering the thermal and flow characteristics of the system, demonstrating their role in modifying heat transfer and fluid motion. These investigations collectively contribute to a deeper understanding of the interplay between electrical conductivity, thermal effects, and chemical reactions in fluid dynamics.

The key findings suggest that an increase in the material parameter leads to an enhancement in velocity, couple stress, Sherwood number, and Nusselt number. Additionally, temperature, concentration, and shear stress exhibit a dual nature, where they increase under certain conditions and decrease under others, indicating a complex interplay between different governing factors.

Furtermore, the research presented in [3] analyzed the influence of Ohmic heating and viscous dissipation on an unsteady natural convective flow over an impulsively started vertical plate. This study also incorporated the effects of a porous medium, radiation, and chemical reactions to provide a more comprehensive understanding of the system's behavior. The findings revealed that an increase in Ohmic and viscous heating contributes to the expansion of the velocity boundary layer, thereby facilitating fluid motion. However, excessive Ohmic heating was observed to reduce the temperature, suggesting a competing effect between heat generation and dissipation. Additionally, a stronger magnetic field was found to lower the temperature profile, likely due to the suppression of fluid motion and a reduction in convective heat transfer. These insights highlight the intricate relationships between thermal, fluid, and electromagnetic parameters in such flow systems.

Swain [4] investigated heat and mass transfer effects in an electrically conducting viscous fluid subjected to a transverse magnetic field over an exponentially stretching sheet in a porous medium. This research focused on the variations of non-dimensional parameters such as the Prandtl number, magnetic field strength, radiation parameter, and concentration. Additionally, [5] reported that enhancing porous media properties leads to an increase in surface shear stress. It was also observed that shear-thinning fluids exhibit higher velocity compared to shear-thickening fluids, whereas the opposite trend was noted in temperature and concentration distributions.

Anderson [6] investigated the flow behavior of a viscous ferrofluid over a stretching sheet influenced by a magnetic dipole. The findings suggest that the introduction of a magnetic field significantly influences fluid motion, causing it to slow down in comparison to a purely hydrodynamic scenario. This reduction in velocity is attributed to the Lorentz force, which acts as a resistive force opposing the fluid flow. As a consequence of this deceleration, skin friction at the surface increases due to higher resistance encountered by the fluid. Simultaneously, the heat transfer rate at the sheets decreases, likely due to the suppression of convective transport mechanisms. This highlights the crucial role of magnetic fields in modifying both the flow dynamics and thermal characteristics of the system.

[8] Discussed the insignificant effects on the concentrationn of the fluid flow at any point of the flow. Also [8] examined that the behaviour of velocity and temperaturee in the absence and in presence of the Ohmic effect and effects of magnetic field. [9] examined the influence of the magnetic parameter on temperature reduction in an electrically conducting viscoelastic fluid subjected to a transverse magnetic field. The study considered the presence of a chemical reaction and a porous matrix, along with the effects of a heat source or sink. It was observed that the magnetic parameter contributes to a decrease in temperature under these conditions.

Furthermore, [10] analyzed the impact of inclination angle on thermal behavior by considering two different temperature boundary conditions. The results indicate that an increase in the inclination angle enhances the influence of gravitational forces on the fluid flow. This enhanced gravitational effect promotes stronger fluid acceleration along the inclined surface, which in turn leads to a reduction in the thickness of the thermal boundary layer. The thinning of this layer suggests more efficient heat transfer, as the temperature gradient near the surface becomes steeper. Consequently, the interaction between buoyancy forces and the inclined orientation plays a crucial role in shaping the thermal behavior of the system.

The research presented in [11] reveals that the temperature field is inversely related to both the thermal relaxation parameter and the Prandtl number. This implies that as these parameters increase, the overall temperature within the system decreases. The thermal relaxation parameter governs the time delay in heat conduction, meaning that higher values lead to slower heat propagation, thereby reducing the temperature. Similarly, a higher Prandtl number, which represents the ratio of momentum diffusivity to thermal diffusivity, indicates that heat diffuses more slowly than momentum, resulting in a lower temperature field.

Furthermore, the study conducted in [12] highlights that an increase in the variable viscosity parameter negatively impacts the velocity distribution, causing it to decline. This suggests that variations in viscosity significantly influence the fluid's resistance to motion. Additionally, the concentration distribution exhibits a direct dependence on the Soret number, meaning that as the Soret number increases, concentration levels rise due to enhanced mass diffusion caused by temperature gradients. In contrast, an increase in the Schmidt number, which represents the ratio of momentum diffusivity to mass diffusivity, leads to a decrease in concentration distribution. This occurs because higher Schmidt numbers indicate a reduced molecular diffusion rate, thereby limiting the spread of species within the fluid. These findings underscore the complex interplay between thermal, momentum, and mass diffusion parameters in fluid flow system.

As we can observe many of the researcher formulated the problem by taking different type of fluid with Ohmic effect. In our problem formulation we are considering Ohmic effect with inclined stretching sheet and dielectric liquid as a cooling media. This type of situation is very useful in practically like the use of inclined stretching sheets with dielectric liquid coolant in porous media offers potential benefits such as improved temperature control, enhanced process efficiency, and better product quality across a range of industrial applications including materials processing, mining, and fuel production.

Imagine a scenario where a smooth, unyielding surface is tilted at an angle θ to the horizontal, causing a continuous flow of an incompressible, non-conducting liquid through the porous media. This flow, devoid of any heat transfer, is directed by balanced forces along the x and y axes, effectively counteracting gravity's influence. The surface undergoes controlled stretching, its velocity $u_w(x)=cx$ gradually increasing with distance from the starting point. Adding to this setup, an electric dipole is positioned at a distance from the x-axis, placed some distance away from the surface along the y-axis as shown in Figure 1. These parameters define the governing principles governing this specific physical arrangement.

3. Methodology

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \qquad (1.1)$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+\lambda_1\left[u^2\frac{\partial^2 u}{\partial x^2}+v^2\frac{\partial^2 u}{\partial y^2}+2uv\frac{\partial^2 u}{\partial x\partial y}\right]$$
$$=\frac{P}{\rho}\frac{\partial E}{\partial x}+v\frac{\partial^2 u}{\partial y^2}+g\beta^*(T_c-T)sin\theta-\frac{\mu}{K}u \qquad (1.2)$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{K}{\rho C_P}\frac{\partial^2 T}{\partial y^2}+\frac{K}{\rho C_P}\left[\mu\left(\frac{\partial u}{\partial x}\right)^2+2\mu\left(\frac{\partial v}{\partial y}\right)^2\right]+\frac{\mu_P}{c_P}u^2 \qquad (1.3)$$

The different notations are defined within the nomenclature section.

The temperature boundary conditions are derived from the temperature at the boundary, referred to as PST. These conditions are set based on the thermal characteristics observed at the boundary and are formulated as follows

$$\left.\begin{matrix} u(x,0)=cx, v(x,0)=0 \quad T(x,0)=T_w=T_c-A\left(\frac{x}{L}\right)\ in\ PST\ u(x,\infty)\to 0,\ T(x,\infty)\to T_c \end{matrix}\right\} \qquad (1.4)$$

The positive constants A and D are important parameters which plays a crucial role. $L=\sqrt{\frac{v}{c}}$ is the characteristic length.

The fluid temperature is represented by T, the curie temperature by T_c, and the temperature of the stretching sheet by T_w. The interaction between the electric field and the dielectric liquid leads to modifications in the flow behavior due to the influence of the electric dipole. This phenomenon arises from the presence of a scalar electric potential source, which governs the distribution of electric forces within the liquid, ultimately affecting its movement and dynamics.

$$\emptyset=\left(\frac{x}{(x^2+(y+a)^2)}\right)\frac{\alpha'}{2\pi} \qquad (1.5)$$

where α' is the electric field strength at the source. The components of the electric field E are as follows

$$E_x=-\frac{\partial\emptyset}{\partial x}=\frac{\alpha'}{2\pi}\left(\frac{x^2-(y+a)^2}{x^2+(y+a)^2}\right) \qquad (1.6)$$

$$E_y=-\frac{\partial\emptyset}{\partial y}=\frac{\alpha'}{2\pi}\left(\frac{2x(y+a)}{x^2+(y+a)^2}\right) \qquad (1.7)$$

$$E=\left[\left(\frac{\partial\emptyset}{\partial x}\right)^2+\left(\frac{\partial\emptyset}{\partial y}\right)^2\right]^{\frac{1}{2}} \qquad (1.8)$$

A linear equation approximates the variation of polarization P with temperature T.

$$P=\varepsilon_0(\varepsilon_r-1) \qquad (1.9)$$

Where $\varepsilon_0\ and\ \varepsilon_r$ denote the absolute and relative dielectric permittivity respectively. Andersson [6] introduced the following non- dimensional variables

$$(\xi,\eta)=\left(\frac{c}{V}\right)^{\frac{1}{2}}(x,y),\ (U,V)=\frac{(u,v)}{\sqrt{cV}} \qquad (1.10)$$

$$\theta(\xi,\eta)=\frac{T_c-T}{T_c-T_w}=\ \theta_1(\eta)+\xi^2\theta_2(\eta)\quad in\ PST\ case \qquad (1.11)$$

Where, $T_c-T_w=A\left(\frac{x}{L}\right)\quad in\ PST\ case$ (1.12)

When employing (1.9) through (1.12), the equations for the boundary layer (1.1–1.3) have the following form:

$$\frac{\partial U}{\partial\xi}+\frac{\partial V}{\partial\eta}=0 \qquad (1.13)$$

$$U\frac{\partial U}{\partial\xi}+V\frac{\partial U}{\partial\eta}+\lambda_1 c\left[U^2\frac{\partial^2 U}{\partial\xi^2}+v^2\frac{\partial^2 U}{\partial\eta^2}+2UV\frac{\partial^2 U}{\partial\xi\partial\eta}\right]$$
$$=\frac{\partial^2 U}{\partial\eta^2}-\frac{2\beta\xi}{(\eta+\alpha)^4}(\theta_1+\xi^2\theta_2)+G_r\xi sin\theta(\theta_1+\xi^2\theta_2)=\frac{\partial^2 U}{\partial\eta^2}-\frac{2\beta\xi}{(\eta+\alpha)^4}(\theta_1+\xi^2\theta_2)+Gr\xi sin\theta(\theta_1+\xi^2\theta_2)-\alpha_2 U \qquad (1.14)$$

$$P[2U\xi\theta_2+V(\theta_1'+\xi^2\theta_2')]\ =\theta_1''+$$

$$\xi^2\theta_2'' - \lambda\left(\left(\frac{\partial u}{\partial \eta}\right)^2 + 2\left(\left(\frac{\partial v}{\partial \eta}\right)^2\right)\right) - \lambda_2 U^2 \quad (1.15)$$

The boundary conditions derived from (5.2.4) is now specified as follows

$U(\xi,0) = \xi, \quad V(\xi,0) = 0, \ \theta_1(\xi,0) = 1, \quad \theta_2(\xi,0) = 0 \quad in \quad PST$ (1.16)

$\theta_1'(\xi,0) = -1, \ \phi_2'(\xi,0) = 0, U(\xi,\infty) \to 0, \quad \theta(\xi,\infty) \to 0 \quad in \ \ PHF$ (1.17)

$\lambda_2 = \frac{\mu_p \gamma^2 U^2}{\rho c_p k (T_c - T_w)}$ is Ohmic parameter

$\alpha_2 = \frac{\mu}{kc}$ is Permeability parameter

By introducing the stream function

$(\xi,\eta) = \xi f(\eta).$

(1.18)

Therefore we obtain

$$U = \frac{\partial \Psi}{\partial \eta} = \xi f'(\eta), \quad V = \frac{\partial \Psi}{\partial \xi} = -f(\eta) \quad (1.19)$$

Here the prime symbol represents differentiation with respect to η.

We get the following boundary value problem by using (1.10), (1.11) and (1.17) in (1.14) and (1.15).

$$f'''(\gamma_1 f^2 - 1) + f'^2 - ff'' - 2\gamma_1 ff'f'' - Gr\theta_1 sin\theta + \alpha_2 f' - \frac{2\beta(\theta_1(\eta))}{(\eta+\alpha)^4} = 0 \quad (1.20)$$

$$\theta_1'' - 2\lambda f'^2 + Prf\theta_1' = 0 \quad (1.21)$$

$$\theta_2'' - Pr\,(2f'\theta_2 - f\theta_2') - \lambda f''^2 - \lambda_2 f'^2 = 0 \quad (1.22)$$

$$f = 0, \quad f' = 1, \ \theta_1 = 1, \ \theta_2 = 0 \ at \ \eta = 0 \quad (1.23)$$

$$f' \to 0, \quad \theta_1 \to 0, \quad \theta_2 \to 0, \quad as \quad \eta \to \infty \quad (1.24)$$

At the sheet the dimensionless form of the shear stress τ which is nothing but local skin friction coefficient denoted by C_f is given by

$$C_f = \frac{-2\tau_{xy}}{\rho(cx)^2} = -2f''(0)Re_x^{\frac{-1}{2}}$$

Fixing the surface temperature it is possible to calculate the local heat flux and is given by

$$Nu_x = -Re_x^{\frac{1}{2}}[\theta_1'(0) + \xi^2\theta_2'(0)]$$

The shooting technique and the Runge Kutta Fehlberg (RKF45) method are used to solve set of two point boundary value problems generated by equations (1.20) - (1.22). To satisfy the outer boundary requirement, Newton Raphson's approach is used to alter the trial values of f″ (0), θ_1'(0), θ_2'(0).

4. Result and Discussion

(i) Effect of Pr (Prandtl Number)

Changes in non-dimentional parameter Prantl number can impact the fluid's rheological behavior. In convection, the Prandtl number influences the velocity profiles near a solid boundary. In fluids with lower Prandtl numbers (Pr < 1), such as gases, the influence of viscosity on the velocity profile becomes more significant. This increased effect of viscosity leads to the formation of a thinner velocity boundary layer. This behavior is particularly evident in the PST case, as illustrated in Figure 2, where the reduced thermal diffusivity relative to momentum diffusivity results in distinct boundary layer characteristics.

In natural convection, where fluid motion is driven by density variations caused by temperature gradients, the Prandtl number plays a crucial role in determining the rate of heat transfer. Fluids with lower Prandtl numbers (Pr < 1), such as gases, exhibit enhanced heat transfer rates because thermal diffusion dominates over momentum diffusion. This explains why gases like air (Pr ≈ 0.7) generally have higher heat transfer coefficients in natural convection when compared to most liquids, which have Prandtl numbers greater than one (Pr >1).

As illustrated in Figure 3 for the PST case, fluids with higher Prandtl numbers experience a slower rate of heat transfer. This occurs because a higher Prandtl number leads to the formation of a thicker thermal boundary layer. The increased thickness of this layer reduces the efficiency of convective heat transfer relative to momentum transfer, thereby limiting the overall heat transfer process. The impact of this effect on heat transfer behavior is clearly demonstrated in Figure 3.

(ii) Effect of Gr (Grashoff number)
The Grashof number is a dimensionless quantity that represents the balance between buoyancy and viscous forces in fluid flow caused by density variations. A higher Grashof number signifies that buoyancy forces are gaining prominence over viscous forces, influencing the overall fluid motion. As Groshof number increases, the buoyancy-induced flow becomes more pronounced. The velocity of the fluid will generally increase as shown in the Figure 4 which represents velocity profile in PST leading to more vigorous convective currents in the fluid.

The interaction between viscoelastic properties and the Grashof number generally results in reduced heat transfer rates, particularly in laminar flow conditions. As the Grashof number increases, buoyancy-driven flow enhances mixing and convective heat transfer. However, due to the fluid's elastic nature, the temperature profile decreases, as illustrated in Figure 5.

(iii) Effect of γ_1(Viscoelastic Parameter)
The viscoelastic parameters of a fluid have a significant influence on both flow and heat transfer behaviors. Viscoelastic fuids have properties of both viscous liquids and elastic solids. Understanding how these parameters affect flow and heat transfer is crucial in various engineering applications. The ratio of viscosity to elasticity determines whether the fluid behaves more like a liquid or a solid. When elasticity dominates, the fluid resists deformation and flow, behaving more like a solid. So this affects on velocity which slow downs the motion of the fluid. This can be observed in the Figure 6.

Viscoelastic fluids often exhibit stress relaxation behaviour, where the material gradually returns to its original state after experiencing a deformation. This phenomenon can influence transient flows and the manner in which stress propagates through the fluid. The heat convection capability of a viscoelastic fluid is directly affected by its flow behavior. When elasticity dominates the flow, heat transfer tends to be less efficient compared to a purely viscous fluid, as the fluid's resistance to deformation inhibits effective thermal convection. Consequently, this results in an increase in the temperature profile, as observed in Figure 7 for the PST case.

Effect of β (Dielectric interaction parameter) Figure 8 illustrates the velocity profile corresponding to different values of the dielectric interaction parameter. It is evident from the figure that an increase in the dielectric interaction parameter leads to a decrease in the velocity profile while simultaneously causing an increase in the temperature profile. This behavior can be attributed to the strengthening of electrostatic forces as the dielectric interaction parameter rises. The intensified electrostatic effects create resistance to fluid motion, thereby slowing down the flow. Consequently, the reduced velocity leads to higher thermal energy retention within the fluid, resulting in an increase in the temperature profile. As the fluid flows slowley, there will be a heat generation within the fluid. This leads to increase in heat transfer as shown in the Figure 9 of PST case.

(iv) Effect of λ_2 (Ohmic Parameter)

Decrease in Velocity

As the Ohmic parameter rises, the temperature decreases due to the improved electrical conductivity or decreased resistance within the fluid as shown in the Figure 10. Increased Ohmic parameter can also find application in fields like electrochemical engineering, where it enhances processes such as electrodialysis for desalination or wastewater treatment. In these applications, higher Ohmic parameters facilitate more efficient electrolysis and ion transport, leading to improved separation and purification processes.

This is because an increase in the Ohmic parameter could induce additional resistive effects within the porous medium. This increase in resistance might hinder the flow of the conducting fluid through the medium. The combined influence of higher resistance due to increased Ohmic effects, coupled with the inherent resistance offered by the porous structure characterized by the Permeability parameter, could result in a decrease in fluid velocity within the medium.

In practical applications, engineers and scientists consider these factors when designing systems involving electrically conductive fluids to ensure that the Ohmic effect is properly managed and understood in relation to the fluid flow and temperature distribution.

(v) Effect of α_2 (Permeability Parameter)

Higher Permeability in a porous medium can enhance convective heat transfer by facilitating better fluid flow and increasing the effective surface area for heat exchange. This can be observed in Figure 11 and 12 of PST case.

(vi) Effect of θ (Angle of Inclination)

The inclusion of the angle of inclination in the scenario adds another dimension to the fluid flow and heat transfer dynamics within the porous medium while an increase in the angle of inclination can potentially alter flow patterns, it might not necessarily lead to a straightforward decrease in temperature. Instead, the impact could vary based on the combined influence of all parameters. Figure 13 shows velocity profiles when angle of inclination is increased. As we can observe from the figures that velocity is increasing with the increase in angle of inclination. This is because Changes in the angle of inclination affect the dominance of buoyancy-driven flow changes. So, increase in inclination promotes preferential flow pathways. Because of this the momentum boundary layer thickness increases.

Depending on the interplay between these factors, including the angle of inclination, there could be scenarios where an increase in the inclination angle moderates or changes the temperature distribution within the porous medium. Figure 14 shows decrease in temperature profile when angle of inclination is increased. This leads to the reduced thermal boundary layer thickness.

5. Conclusion

The present study is used numerical analysis to determine the impact of Ohmic heating on heat and flow of a viscoelastic dielectric liquid over an inclined stretching sheet. We have following conclusions.

- ❖ An increase in the Ohmic parameter induces additional resistive effects within the porous medium. This increase in resistance will hinder the flow of the conducting fluid through the medium. The combined influence of higher resistance due to increases Ohmic effects, coupled with the inherent resistance offered by the porous structure resulting in a decrease in fluid velocity within the medium. Higher Ohmic parameter can intensify the joule heating effect within the conducting fluid. As the electrical resistance also increases, leading to more significant heat generation within the fluid. The increased heat generation due to higher Ohmic effects, combined with potential limitations on fluid flow, might result in elevated temperature within the porous medium.

- ❖ The Prantl number influences the ratio of momentum diffusivity to thermal diffusivity. Changes in Prantl number altered the balance between momentum and thermal diffusion, potentially impacting the heat transfer characteristics within the fluid.
- ❖ Higher viscoelastic parameter increases, the fluid's reduced ability to flow easily leads to decreased velocities. Simultaneously, the increased internal friction and energy dissipation cause a rise in the fluid's temperature, leading to an increase in heat.
- ❖ Permeability is a key parameter in understanding and modeling fluid flow through porous media. It influences both the velocity and temperature distributions. As Permeability parameter increases then velocity decreases and temperature increases. This result must be considered carefully when designing systems involving porous materials, particularly in fields like geology, petroleum engineering, and soil mechanics.
- ❖ To achieve control on heat transfer the non-dimensional parameters like Prantl number, dielectric interaction parameter, Ohmic parameter, Permeability parameter, angle of inclination and viscoelastic parameter should be kept at minimum and Grashoff number should be maximum.
- ❖ To achieve control on Fluid velocity Viscoelastic parameter should be maximum and all other parameters should be minimum.
- ❖ The increase in Prantl number, Grashoff number and angle of inclination shows decrease in temperature. Whereas the other parameters dielectric interaction parameter, Viscoelastic parameter, Permeability parameter shows opposite behavior.
- ❖ Increase in Prantl number, Dielectric interaction parameter, Viscoelastic parameter and Permeability parameter shows decrease in velocity profile.

Figure 1 Physical configuration of the problem

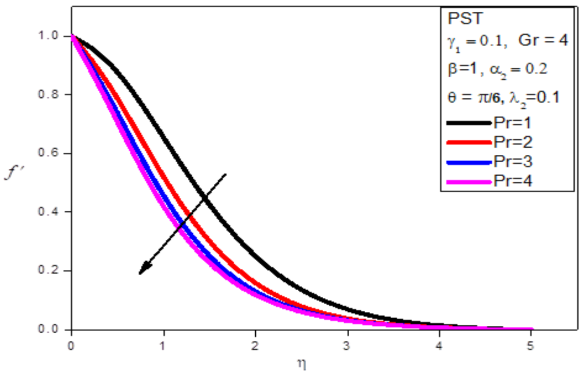

Figure 2 Effect of Variation Prandtl number on Velocity in PST

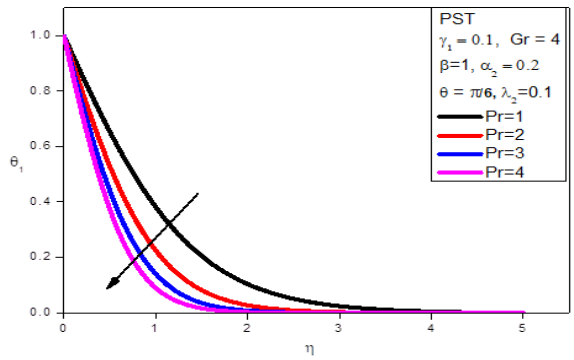

Figure 3 Effect of Variation of Prandtl on Temperature in PST

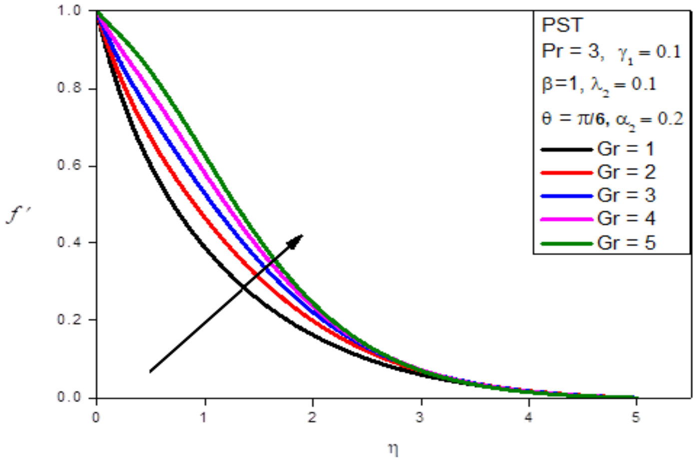

Figure 4 Effect of Gr on Velocity in PST

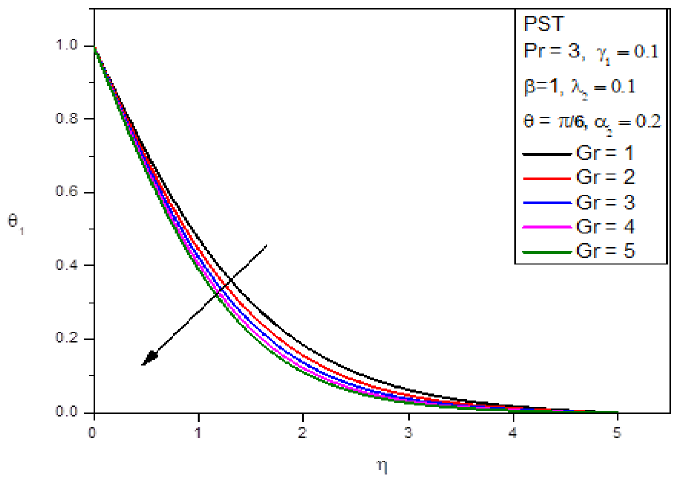

Figure 5 Effect of Gr on Temperature in PST

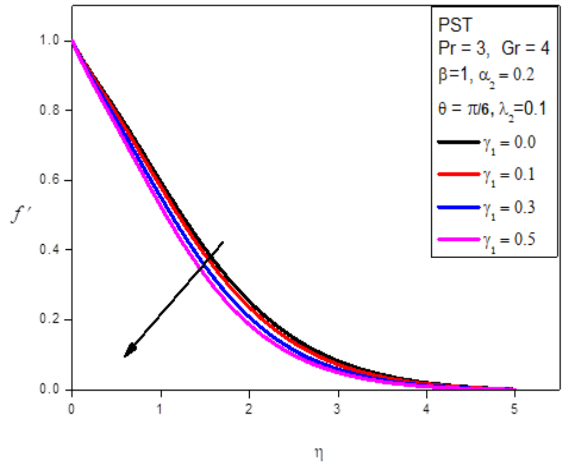

Figure 6 Effect of γ_1 on Velocity in PST

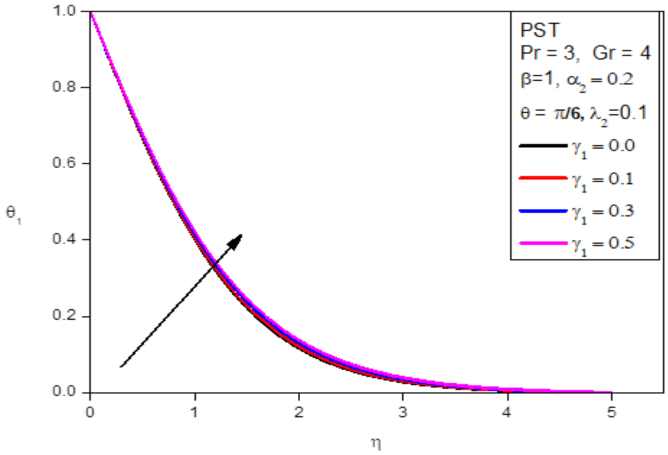

Figure 7 Showing effect of γ_1 on Temperature in PST

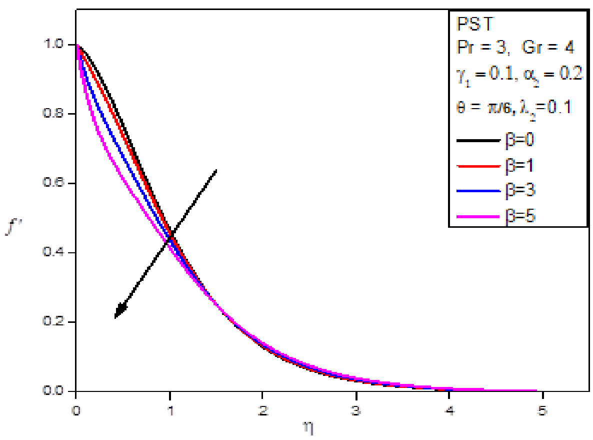

Figure 8 Showing effect of β on Velocity in PST

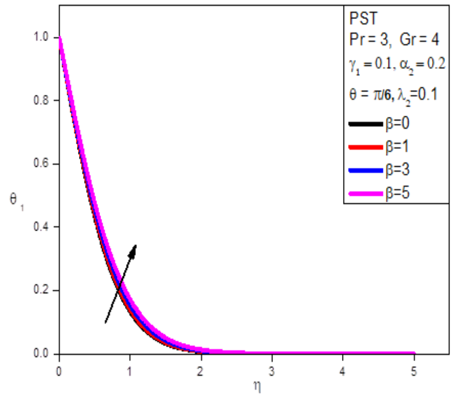

Figure 9 Effect of β on Temperature in PST

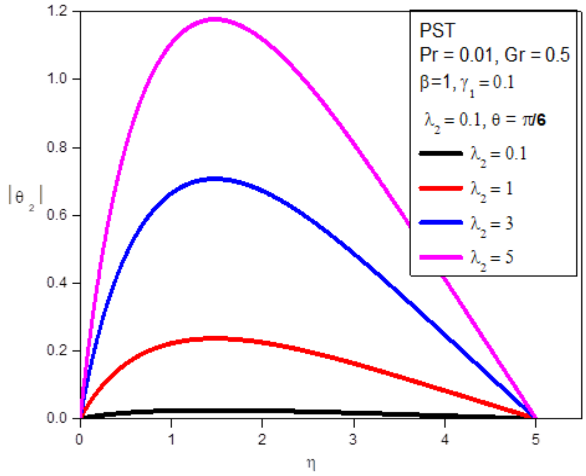

Figure 10 Effect of λ_2 number on Temperature in PST

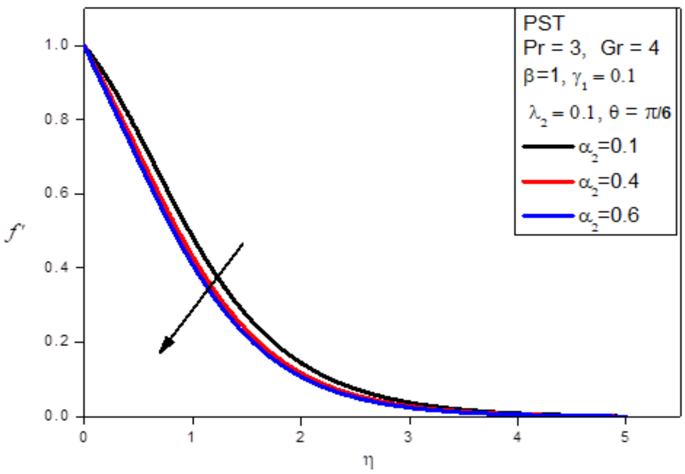

Figure 11 Effect of α_2 number on Velocity in PST

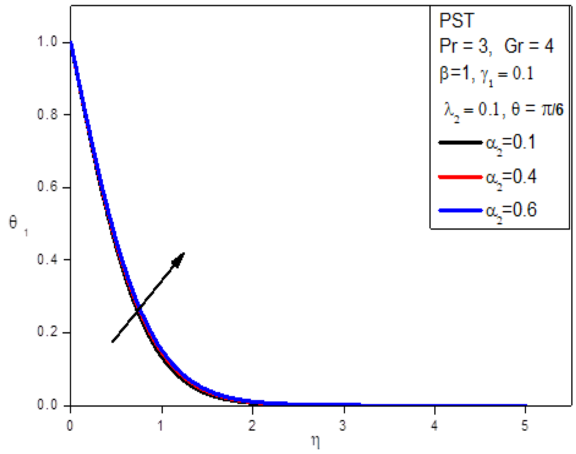

Figure 12 Effect of α_2 number on Temperature in PST

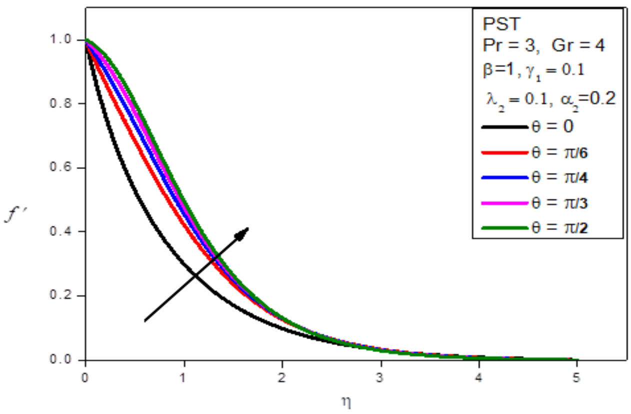

Figure 13 Effect of θ number on Velocity in PST case

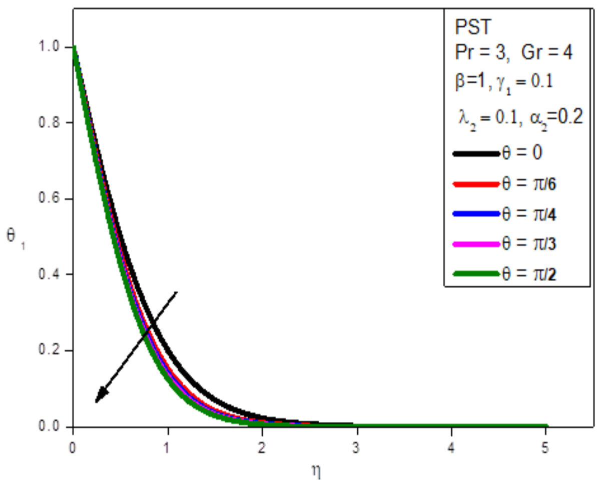

Figure 14 Effect of θ number on Temperature in PST

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