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PROBLEM OF MIXED CONVECTIVE FLOW OF A VISCOELASTIC FLUID IN AN INCLINED CHANNEL WITH PERMEABLE WALLS UNDER THE INFLUENCE OF ACCELERATION DUE TO GRAVITY

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ABSTRACT

Various parameters that influence the flow entities in the case of mixed convection flow of a visco elastic fluid in an inclined channel under the influence of acceleration due to gravity has been examined in detail in this paper. It is observed that, as the cross flow Reynolds number increases, the temperature decreases. Further, for higher values of such cross flow Reynolds Number, it is seen that the temperature remains constant and only after considerable distance away from the boundary, the temperature increases. Further, it has been noticed that, as the cross flow Reynold's number increases, the velocity decreases. Also, for the higher values of cross flow Reynold's number a backward flow is also noticed and as the angle of inclination increases, the velocity increases. Further, the Prandtl number is observed to be inversely related to the temperature. In contrast with the earlier conclusion, it is seen that for larger values of the Prandtl number, the change in temperature is not that significant at the initial stages but at very far distance from the boundary, appreciable change is noticed. It has been noticed that, as the Reynolds number increases, a decreasing trend in the velocity of the fluid has been seen. Further, the angle of inclination appears to have a profound effect on the velocity field. Though the velocity increases when the plate is inclined, the profiles are found to be distinct and are widely dispersed when the bounding surface is held horizontal. Also, the visco elasticity of the fluid and the velocity are inversely related to each other while, the Grashoff number and the velocity of the fluid are directly proportional.

Key words: *Visco elasticity, cross flow Reynolds Number, Darcy Number, Second grade fluid.*

INTRODUCTION:

Non-Newtonian Fluid Mechanics has made significant strides in recent years and there is a fast growing belief that the many provocative experimental phenomena and dilemmas now have a realistic possibility of being explained theoretically. An attempt is being made in this paper to illustrate such an optimistic thought in advocating heat transfer problems that occur in several industrial applications.

Non-Newtonian fluid mechanics has had to be point of concern with the development of general constitutive equations for viscoelastic fluids. These constitutive equations should in principle lead to the definition of flow properties that need to be measured to define the viscoelastic fluid (rheometry) and to the development of the equivalent Navier Stokes equations for the solution of all possible boundary value along with initial value problems that arises in several situations wherein heat and mass transfer takes place. The process is completed by solution of the appropriate equations, where the methods of computational fluid mechanics have been required as a last resort. However, some of the analytical methods for complex flows of viscoelastic fluids generally predict the nature of flow field and gives rise to more or less accurate solution though not perfect solution. In all such situations, the methodology various strands of activity and it will be necessary to consider. For example, we shall need to be quite specific about the experimental conditions pertaining to the relevant phenomena. The flows are invariably complex and the 'experimental dilemmas clearly refer to *complex* flows, where the flow domain sometimes often involves abrupt changes in geometry, and where the flow strength is high enough to permit a terminology which majors on 'high Weissenburg numbers' and 'high Deborah numbers'. This is of course reasonable and not unrealistic, but it nevertheless needs to be stated.

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Therefore now the question that arises is to address the situation "How do elastic liquids behave in complex flows?" and it is immediately apparent that the answer must involve a consideration of how the same liquids behave in simple flows, so that obtaining rheometrical data on the test liquids is an essential part of the exercise. Such data, when available, serve more than one useful purpose; they certainly provide a foundation set of data, which must be accommodated in the associated mathematical model for the test liquids. That is to define a perfect constitutive equation, which is an essential ingredient in any theoretical resolution of the experimental dilemmas, has to be consistent with the rheometrical data. Indeed, if the model cannot simulate behaviour in simple flows, what chance does it have in complex flows?! Clearly, the choice of constitutive equation is central to the whole operation and this choice is far from trivial or obvious. Indeed, a constitutive model which satisfies the dual constraints of tractability and quantitative (or even semi quantitative) prediction may not exist! But that shouldn't and doesn't prevent a search for this missing link'; but it is wise to be aware of the possibility of disappointment.

The constitutive relation that has been proposed for the fluid under consideration needs to be solved in conjunction with the stress equations of motion and the equation of continuity and then to predict and explain the experimental phenomena and dilemmas. Analytic solutions are out of the question so far as complex flows are concerned and Computational Rheology is now an established, if fairly recent science, which seeks theoretical, answers to provocative experiments and phenomena.

The model that has been considered herein this paper is of second order fluid whose constitutive relation has been proposed by Noll. The relation involves viscoelasticity and also covers the concept of cross viscosity.

Flow through porous media has been the subject of considerable research activity in recent years because of its several important applications notably in the flow of oil through porous rock, the extraction of geothermal energy from the deep interior of the earth to the shallow layers, the evaluation of the capability of heat removal from particulate nuclear fuel debris that may result from a hypothetical accident in a nuclear reactor, the filtration of solids from liquids, flow of liquids through ion-exchange beds, drug permeation through human skin, chemical reactor for economical separation or purification of mixtures and so on.

Due to wide ranging applications in the fields of Physics, Chemistry, and Chemical Technology and in situations demanding efficient transfer of mass over inclined beds, the viscous drainage over an inclined rigid plane has been the subject of considerable interest to both theoretical and experimental investigators during the last several years. In all experiments, where the transfer of viscous liquid from one container to another is involved, the rate at which the transfer takes place and the thin film adhering to the surfaces of the container is to be taken into account for the purpose of chemical calculations. Failure to do so leads to experimental error. Hence there is need for such analysis. The most important concept is that of skin friction which affects the boundaries which normally occur in situations of chemical reactors and material transfer from one reactor to another reactor.

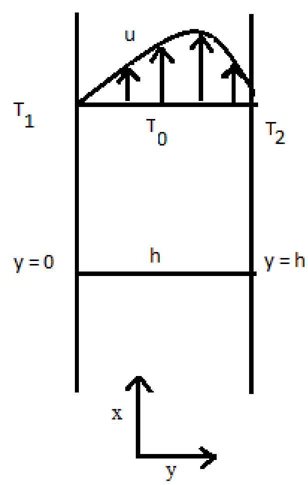
In many chemical processing industries generally slurry adheres to the reactor vessels and gets consolidated. As a result of this, the chemical compounds within the reactor vessel percolates through the boundaries causing loss of production and then consuming more reaction time. The slurry thus formed inside the reactor vessel often acts as a porous boundary for the next cycle of chemical processing.

Flow in a porous medium can be considered as an ordered flow in a disordered geometry. The transport process of fluid through a porous medium involves two substances, the fluid and the porous matrix, and therefore it will be characterized by specific properties of these two substances. A porous medium usually consists of a large number of interconnected pores each of which is saturated with the fluid. The exact form of the structure, however, is highly complicated and differs from medium to medium. A porous medium may be either an aggregate of a large number of particles such as sand or gravel or solid containing many capillaries such as a porous rock. When the fluid percolates through a porous material, because of the complexity of microscopic flow in the pores, the actual path of an individual fluid particle cannot be followed analytically. In all such cases, one has to consider the gross effect of the phenomena represented by a macroscopic view applied to the masses of fluid, large compared to the dimensions of the pore structure of the medium. The process can be described in terms of equilibrium of forces. The driving force necessary to move a specific volume of fluid at a certain speed through a porous medium is in equilibrium with the resistance force generated by internal friction between the fluid and the pore structure. This resistance force is characterized by Darcy's semi-empirical law established by Darcy [1]. The simplest model for flow through a porous medium is the one dimensional model derived by Darcy [1]. Obtained from empirical evidence, Darcy's law indicates that for an incompressible fluid flowing through a channel filled with a fixed, uniform and isotropic porous matrix, the flow speed varies linearly with longitudinal pressure variation. Subsequently, Dupuit and Frochheimer presented empirical evidence that, the Darcy law, or the linearity between speed and pressure variation, breaks down for large enough flow speed (a compilation of several experimental results) is presented by MacDonald *et al.* [2]. This was emphasized later by Joseph *et al* [3] who stressed force modeled by the Frochheimer acts in a direction opposite to the velocity vector. It follows that, in multidimensional flow, the momentum equations for each velocity component derived using the Frochheimer extended Darcy equation is at least speculative. Later, Knupp and Lage [4] analyzed the theoretical generalization to the tensor permeability case (anisotropic medium) of the empirically obtained Frochheimer extended Darcy unidirectional flow model.

A numerical and experimental investigation of the effects of the presence of a solid boundary and initial forces on mass transfer in porous media was presented by Vafai and Tien [5]. The local volume averaging technique has been used to establish the governing equations. The numerical solution of the governing equations is used to investigate the mass concentration field inside a porous media close to an impermeable boundary. In conjunction with the numerical solution, a transient mass transfer experiment has been conducted to demonstrate the boundary and inertia effects on mass transfer. This was accomplished by measuring the time and space averaged mass flux through a porous medium. The results clearly indicate the presence of these effects on mass transfer through porous media.

Heat transfer in porous medium is gaining utmost importance due to its applicability in geothermal energy extraction, nuclear waste disposal, fossil fuels detection, regenerator bed etc. Understanding the development of hydro dynamic and thermal boundary layers along with the heat transfer characteristics is the basic requirement to further investigate the problem. In 1997 Cheng and Minkowycz [6] had analyzed the steady free convection about a vertical plate embedded in porous dynamics in the form of dissipative inequality (Clausius – Duhem) and commonly accepted the idea that the specific Helmholtz free energy should be a minimum in equilibrium. From the pont of medium applied to heat transfer from dike. Murthy and Singh [7] using method of similarity solution studied the influence of lateral mass flux and thermal dispersion on non - Darcy natural convection over a vertical plate in porous medium. They have discussed the combined effect of thermal dispersion and fluid injection on heat stratification on non - Darcy mixed transfer. Hassain *et al* [8] had studied the effects of thermal dispersion and dissipation effects on non – Darcy mixed convection problems and established the trend of heat transfer rate convection from a vertical plate in porous medium and investigated the flow and temperature fields. Subsequently, Murthy [9] had examined the dispersion while, Kuznetsov [10] investigated the effect of transverse thermal dispersion on forced convection in porous media and identified the situations favorable to heat transfer under dispersion effects. Mohammadien and El-Amin [11] studied the dispersion and radiation effects in fluid saturated porous medium on heat transfer rate for both Darcy and non-Darcy medium. Chamka and Quadri [12] examined the heat and mass transfer characteristics under mixed convective conditions with thermal dispersion without taking MHD into consideration. Cheng and Lin [13] in their observation pointed out that rate of unsteady heat transfer can be accelerated by thermal dispersion. Wang *et al* [14] applied an explicit analytical technique namely homotopy analysis to solve the non-Darcy natural convection over a horizontal plate with surface mass flux and thermal dispersion and obtained a totally analytic and uniformly valid solution.

We consider the laminar mixed convection flow of a viscoelastic fluid through a porous medium in a vertical permeable channel, the space between the plates being h, as shown in Fig.



Geometry of the flow field

It is assumed that the rate of injection at one wall is equal to the rate of suction at the other wall. A rectangular coordinate system (x, y) is chosen such that the x axis is parallel to the gravitational acceleration vector g, but with opposite direction and the y - axis is transverse to the channel walls. The left wall (i.e. at $y=0$) is maintained at constant temperature T_1 and the right wall (i.e. at $y=h$) is maintained at constant temperature T_2, where $T_1 > T_2$. The flow is assumed be laminar, steady and is fully developed, i.e. the transverse velocity is zero. Then, the continuity equation drops to $\frac{\partial u}{\partial x} = 0$.

The fluid under consideration is assumed to be of Rivlin-Ericksen type whose constitutive equation is proposed as

$$S = -pI + \mu A_1 + \alpha_1 A_2 + \alpha_2 A_1^2 \tag{1}$$

Where S is the Cauchy stress tensor, p is the scalar pressure, μ, α_1 and α_2 are the material constants, customarily known as the coefficients of viscosity, elasticity and cross - viscosity, respectively. These material constants can be determined from viscometric flows for any real fluid. A_1 and A_2 are Rivlin-Ericksen tensors and they denote, respectively, the rate of strain and acceleration. A_1 and A_2 are defined by

$$A_1 = \nabla V + (\nabla V)^T \tag{2}$$

$$A_2 = \frac{dA_1}{dt} + A_1 \nabla V + (\nabla V)^T A_1 \tag{3}$$

where $\frac{d}{dt}$ is the material time derivative and ∇ gradient operator and $(\ )^T$ transpose operator. The viscoelastic fluids when modeled by Rivlin-Ericksen constitutive equation are termed as second grade fluids. A detailed account of the characteristics of second – grade fluids is well documented by Dunn and Rajagopal [15]. Later, Rajagopal and Gupta [16] had studied the thermodynamics consideration and it is assumed that:

$$\mu \geq 0 \ , \alpha_1 > 0 \text{ and } \quad \alpha_1 + \alpha_2 = 0 \tag{4}$$

The basic equations of momentum and energy governing such a flow, subject to the Boussinesq approximation, are

$$\rho v_0 \frac{du}{dy} = -\frac{dp}{dx} + \mu \frac{d^2u}{dy^2} + \alpha_1 v_0 \frac{d^3u}{dy^3} - \frac{\mu}{k_0} u + \rho g \beta (T - T_0) \tag{5}$$

$$v_0 \frac{dT}{dy} = \alpha \frac{d^2T}{dy^2} \tag{6}$$

where p is the pressure, ρ is the density, μ is the dynamic viscosity of the fluid, g is acceleration due to gravity, β coefficient of thermal expansion, α_1 is the viscoelastic parameter, k_0 is the permeability of the porous medium and v_0 is the transpiration cross flow velocity. Further, here $\frac{dp}{dx}$ is a constant.

The boundary conditions are given by

$$u(0) = u(h) = 0 \, , \ T(0) = T_1 \quad \text{and } T(h) = T_2 \tag{7}$$

Introducing the following non-dimensional variables

$$\bar{y} = \frac{y}{h}, \qquad \bar{u} = \frac{u}{h^2} \quad \text{and} \quad \theta = \frac{T - T_0}{T_2 - T_0}$$

into the equations (5) and (6), we obtain

$$kR \frac{d^3u}{dy^3} + \frac{d^2u}{dy^2} - R\frac{du}{dy} - \frac{1}{Da}u + \frac{Gr}{\mathrm{Re}}\theta + A + G Sin\phi = 0 \tag{8}$$

$$\frac{d^2\theta}{dy^2} - R \Pr \frac{d\theta}{dy} = 0 \tag{9}$$

where $k=\dfrac{\alpha_1}{\rho h^2}$ is the viscoelastic parameter, $R=\dfrac{\rho v_0 h}{\mu}$ is the cross flow Reynolds number, $Gr=\dfrac{g\beta(T_2-T_1)h^3}{\nu^2}$ is the Grashof number, $\mathrm{Re}=\dfrac{\rho U_0 h}{\mu}$ is the Reynolds number, $\Pr=\dfrac{\nu}{\alpha}$ is the Prandtl number, $r_T=\dfrac{T_1-T_0}{T_2-T_0}$ is the wall temperature parameter and $A=-(\dfrac{dp}{dx})\dfrac{U_0\nu}{h^2}$ is the constant pressure gradient.

The corresponding dimensionless boundary conditions are given by

$$u(0)=u(1)=0,$$

$$\theta(0)=r_T \text{ and } \theta(1)=1 \tag{10}$$

Solution: We consider the first – order perturbation solution of the BVP (4) – (6) for small k. Since the constitute equation (1) has been derived up to only the first – order of smallness of k, therefore, the perturbation solution obtained by retaining the terms up to the same order of smallness of k must be quite logical and reasonable. We write

$$u=u_0+ku_1 \tag{11}$$

and

$$\theta=\theta_0+k\theta_1 \tag{12}$$

Substituting equations (11) and (12) into equations (8) and (9) and boundary conditions (10) and then equating the like powers of k, we obtain

Zeroth-order system (k^0) **:**

$$\frac{d^2u_0}{dy^2}-R\frac{du_0}{dy}-\frac{1}{Da}u_0=-\frac{Gr}{\mathrm{Re}}\theta_0-A-GSin\phi \tag{13}$$

$$\frac{d^2\theta_0}{dy^2}-R\Pr\frac{d\theta_0}{dy}=0 \tag{14}$$

Together with boundary conditions

$$u_0(0)=u_0(1)=0\ ,$$

$$\theta_0(0)=r_T \text{ and } \theta_0(1)=1 \tag{15}$$

First-order system (k^1) **:**

$$\frac{d^2u_1}{dy^2}-R\frac{du_1}{dy}-\frac{1}{Da}u_1=-R\frac{d^3u_0}{dy^3}-\frac{Gr}{\mathrm{Re}}\theta_1 \tag{16}$$

$$\frac{d^2\theta_1}{dy^2}-R\Pr\frac{d\theta_1}{dy}=0 \tag{17}$$

Together with boundary conditions

$$u_1(0)=u_1(1)=0$$

and

$$\theta_1(0)=\theta_1(1)=0 \tag{18}$$

Zeroth-order solution (or Solution for a Newtonian fluid):

Solving equations (13) and (14) using the boundary conditions (15), we get

$$\theta_0 = \frac{(1 - r_T e^{R\Pr}) + (r_T - 1)e^{R\Pr y}}{(1 - e^{R\Pr})} \tag{19}$$

$$u_0 = c_1 e^{ay} + c_2 e^{by} + \frac{Gr}{\text{Re}}(f_1 - f_2 e^{R\Pr y}) + ADa + GDaSin\phi \tag{20}$$

where

$$a = \frac{R + \sqrt{R^2 + 4/Da}}{2}, b = \frac{R - \sqrt{R^2 + 4/Da}}{2} \quad f_1 = \frac{(1 - r_T e^{R\Pr})Da}{(1 - e^{R\Pr})},$$

$$f_2 = \frac{(r_T - 1)}{(1 - e^{R\Pr})(R^2\Pr^2 - R^2\Pr - 1/Da)}, \; f_3 = \frac{Gr}{\text{Re}}(f_1 - f_2) + ADa + DaGSin\phi,$$

$$f_4 = \frac{Gr}{\text{Re}}(f_1 - f_2 e^{R\Pr}) + ADa + DaGSin\phi, c_1 = \frac{f_4 - f_3 e^b}{e^b - e^a}, \quad c_2 = \frac{f_3 e^a - f_4}{e^b - e^a}.$$

First-order solution (or Solution for a second-grade fluid) :

Solving equation (17) with corresponding boundary conditions, we obtain

$$\theta_1 = 0 \tag{21}$$

Substituting the equations (20) and (21) into the Eq. (16) and then solving the resulting equation with the corresponding conditions, we get

$$u_1 = c_3 e^{ay} + c_4 e^{by} - f_6 y e^{ay} - f_7 y e^{by} + f_5 e^{R\Pr y}$$

where $f_5 = \frac{Gr}{\text{Re}} \frac{f_2 R^4 \Pr^3}{(R^2\Pr^2 - R^2\Pr - 1/Da)}, f_6 = \frac{Rc_1 a^3}{2a - R} \; f_7 = \frac{Rc_2 b^3}{2b - R}, \; f_8 = f_5 e^{R\Pr} - f_6 e^a - f_7 e^b,$

$$c_3 = \frac{f_8 - f_5 e^b}{e^b - e^a}, \qquad c_4 = \frac{f_5 e^a - f_8}{e^b - e^a}.$$

It can be verified that when $k = 0, R = 0$ and $Da \to \infty$ our results reduces to those given by Aung and Worku (1986).

RESULTS AND CONCLUSIONS:

The effect of cross flow Reynolds number over the temperature distribution has been illustrated in Fig - 1. It is observed that, as the Reynolds number increases, the temperature decreases. Further, for higher values of Reynolds Number, it is seen that the temperature remains constant and only after considerable distance away from the boundary, the temperature increases.

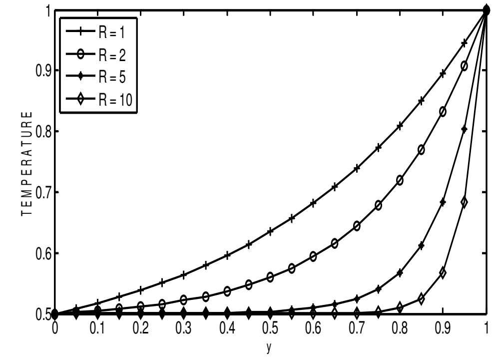


Fig - 1: Effect of Cross Flow Reynolds Number on temperature distribution

The influence of Prandtl number over the temperature distribution has been illustrated in Fig – 2. It is observed that as the Prandtl number increases, a decreasing trend in temperature is observed. In contrast with the earlier conclusion, it is observed that for very large value of the Prandtl number, the change in temperature is not that significant at the initial stages. However, at very far distance from the boundary, appreciable change is noticed.

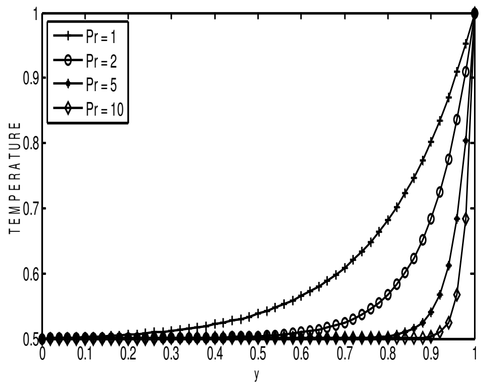


Fig - 2: Effect of Prandtl number on temperature distribution

Fig - 3 and Fig - 4 depicts the influence of wall temperature parameter on the temperature distribution in the fluid medium. It is observed that as the wall temperature parameter increases, the temperature increases. Further, it is seen that as we move away from the lower boundary, the increase in temperature is found to be more steep.

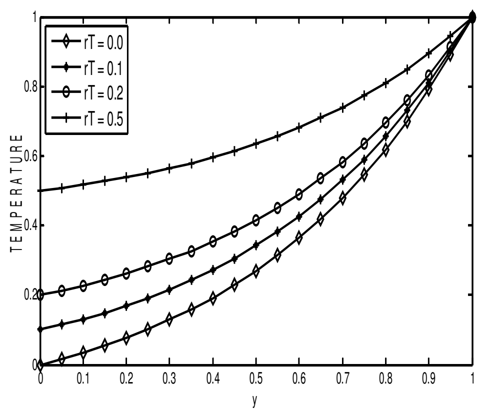


Fig - 3: Influence of wall temperature parameter on temperature distribution when R = 1

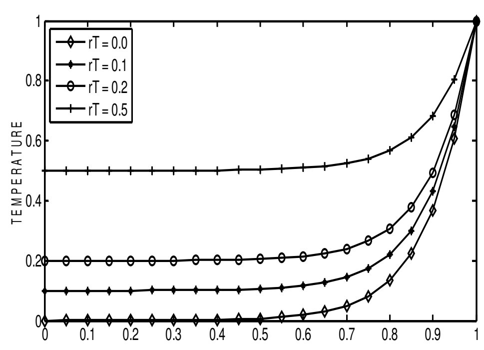


Fig - 4: Influence of wall temperature parameter on temperature distribution when R = 5

The influence of cross flow Reynolds number on the velocity profiles has been illustrated in Fig - 5, Fig - 6, Fig - 7, Fig - 8 and Fig - 9 when the bounding surface is held at different angles of inclination. In each of these illustrations, it has been noticed that, as the Cross flow Reynold's number increases, the velocity decreases. Further, as the Cross flow Reynold's number is at high values, backward flow is also noticed. Also, as the angle of inclination increases, the velocity increases however the flow pattern for the velocity profiles remains unchanged. Increase in the velocity due to the variation in the angle of inclination can also be attributed to the gravitational force that acts on the system. The mathematical model so developed is in agreement with the realistic situation

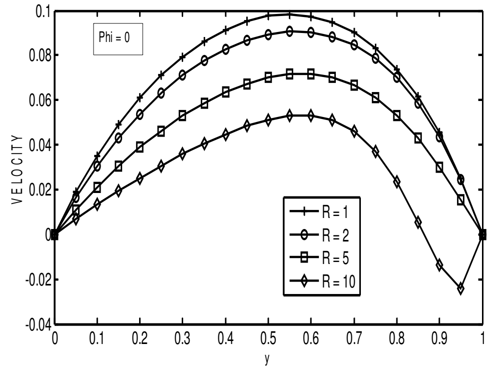


Fig - 5: Contribution of Cross flow Reynolds No. on the velocity profiles

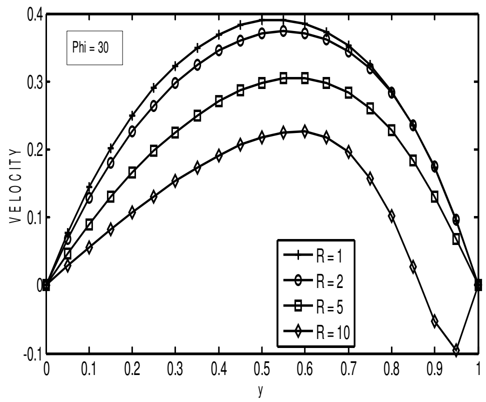


Fig - 6: Contribution of Cross flow Reynolds No. on the velocity profiles

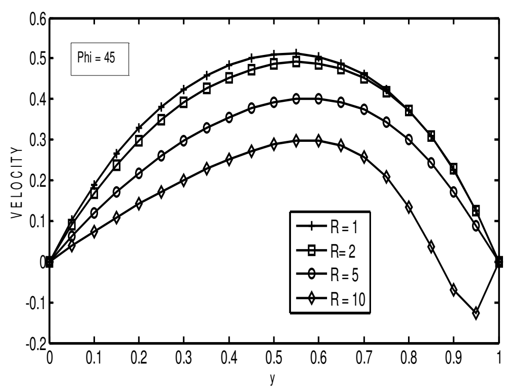


Fig - 7: Effect of Cross flow Reynolds No. on the velocity profiles

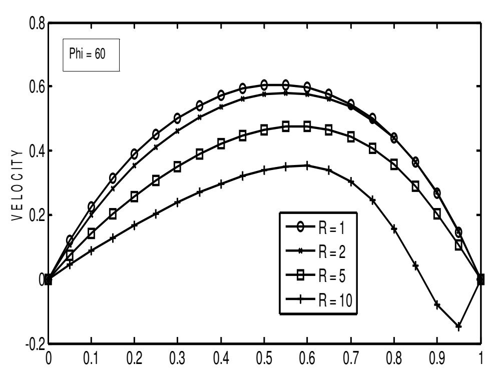


Fig - 8: Influence of Cross flow Reynolds No. on the velocity profiles

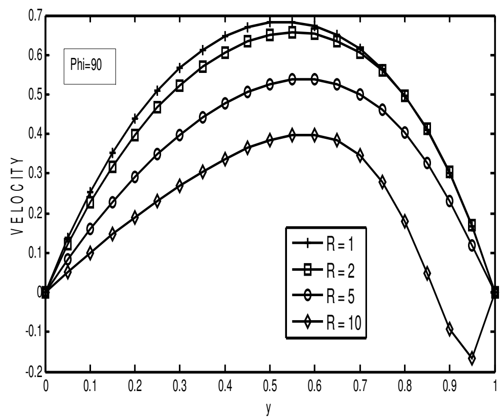


Fig - 9: Contribution of Cross flow Reynolds No. on the velocity profiles

Fig - 10 and Fig - 11 illustrates the influence of Reynolds number on the velocity profiles when the bounding surface is held horizontal and inclined. In each of such situations, it has been noticed that, as the Reynolds number increases, a decreasing trend in the velocity of the fluid has been seen. Further, the angle of inclination appears to have a profound effect on the velocity field. Though the velocity increases when the plate is inclined, the profiles are found to be distinct and are widely dispersed when the bounding surface is held horizontal.

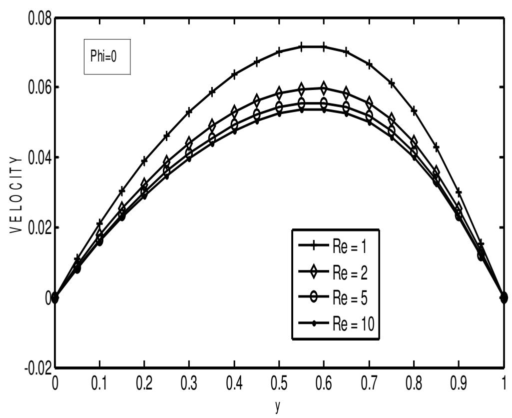


Fig - 10: Influence of Reynolds No. on the velocity profiles

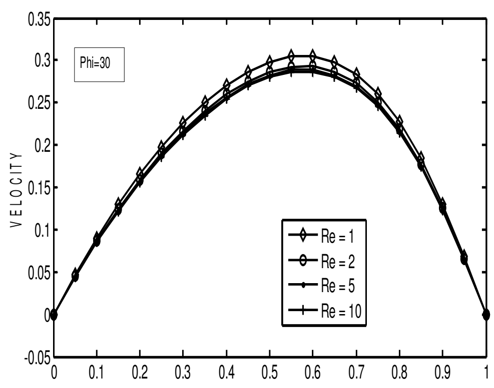


Fig - 11: Effect of Reynolds No. on the velocity profiles

The effect of visco elasticity of the fluid medium over the velocity profiles has been illustrated in Fig - 12, Fig - 13, Fig - 14, Fig - 15 and Fig - 16 when the bounding surface has been held at different angles of inclination. A brief review of the overall situation shows that the angle of inclination has profound effect on the velocity of the fluid medium. It has been noticed that as the angle of inclination increases, the fluid velocity increases which is in conformation with the realistic situation. Also, when examined in each of the situations independently, it is seen that the viscoelasticity of the fluid medium plays an important role. As the viscoelasticity of the fluid increases, the fluid velocity decreases. Such a decrease can be attributed to the strong intra molecular force that is holds the neighboring fluid elements together from draining along the bounding surface. The interesting feature in all the illustrations stated so far is that, the influence of viscoelasticity is not being felt in the initial stages, but at later stage, the dispersion in the velocity profiles in found to be more distinct and profiles are more dispersed.

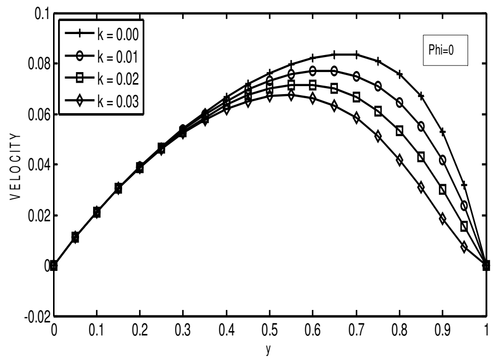


Fig - 12: Influence of Viscoelastic parameter on the velocity profiles

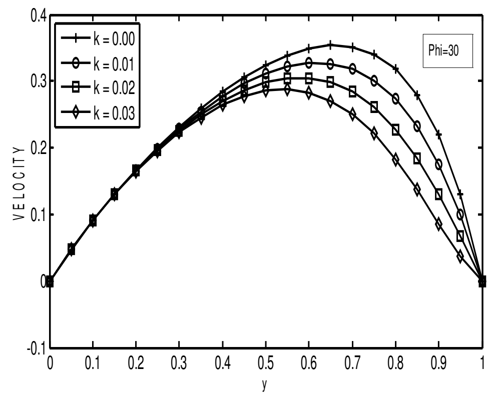


Fig - 13: Contribution of Viscoelastic parameter on the velocity profiles

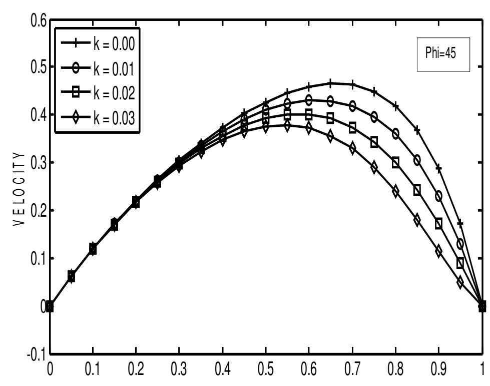


Fig - 14: Effect of Viscoelastic parameter on the velocity profiles

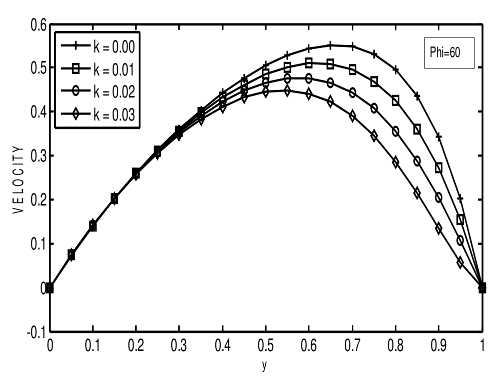


Fig - 15: Influence of Viscoelastic parameter on the velocity profiles

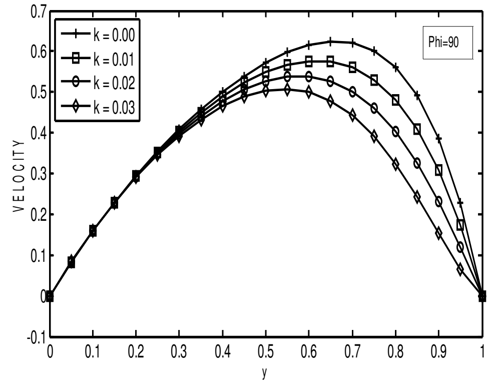


Fig - 16: Contribution of Viscoelastic parameter on the velocity profiles

The effect of the wall temperature parameter on the flow field at different angles of inclination of the bounding surface has been illustrated in Fig. - 17 and Fig - 18. In both the illustrations, the bounding surface has been considered to be horizontal and inclined. When the cases are analyzed independently, it has been noted that, the fluid velocity increases as the wall temperature is increased. Obviously, such a phenomenon is anticipated even in a real life situation. Increase in the wall temperature causes the fluid to become more hot . As a result of this, the intra molecular forces gets weakened and due to such a situation, the fluid tends to drain along the boundary at a faster rate. Also, when the channel is inclined, obviously the gravitational pull acts over the system resulting in the increase of the fluid velocity.

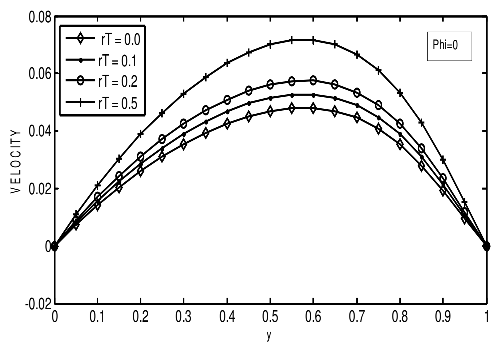


Fig - 17: Effect of wall temperature parameter on the velocity profiles

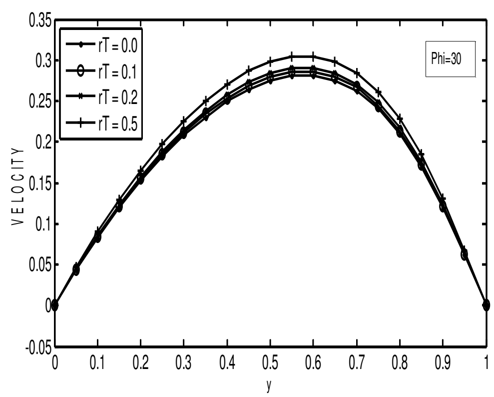


Fig - 18: Influence of wall temperature parameter on the velocity profiles

The consolidated influence of Grashoff number with respect to the angle of inclination of the fluid boundary has been studied in Fig - 19, Fig - 20, Fig - 21 and Fig - 22. An overall situation shows that the flow pattern of velocity profiles though in general remains same, but in realistic terms of numerical values differ. But the pattern in each of the situations remains unaltered. In each of the situation, it is observed that as the Grashoff number increases, the velocity of the fluid medium increases. Such an increase is observed to be more predominant when the angle of inclination of the fluid bed is considered as the gravitational pull also contributes on the entire system. In each of the cases, it is seen that the pattern of the profiles does not change qualitatively but a quantitative change has been noticed. As the angle of inclination increases, the dispersion in velocity profiles appears to be diminishing. Such a diminishing is partly due to the presence of the gravitational pull.

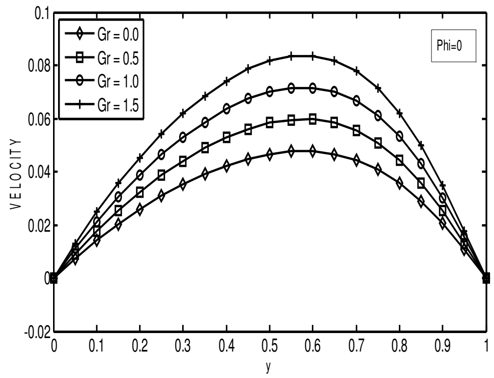


Fig - 19: Effect of Grashoff number on the velocity profiles

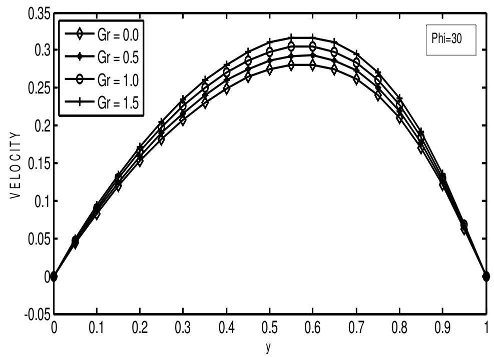


Fig - 20: Influence of Grashoff number on the velocity profiles

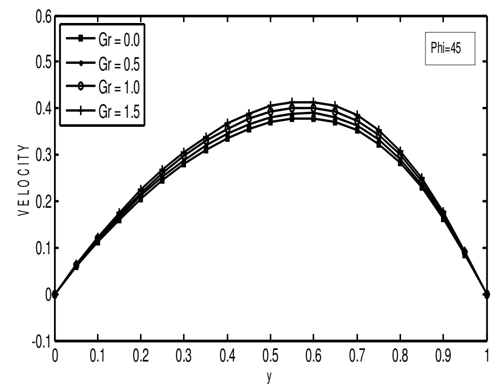


Fig - 21: Contribution of Grashoff number on the velocity profiles

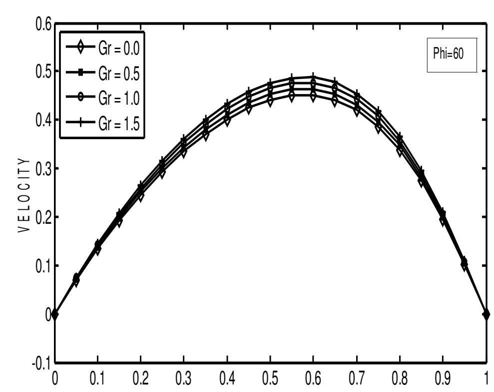


Fig - 22: Effect of Grashoff number on the velocity profiles

The influence of Darcy's parameter with respect to the angle of inclination has illustrated in Fig – 23, Fig – 24, Fig – 25, Fig – 26, and Fig - 27. In each of the representations, it is noted that the increase in Darcy's value is proportional to the velocity. Further, as the fluid bed is inclined, the velocity also increases which is in confirmation with the realistic situation.

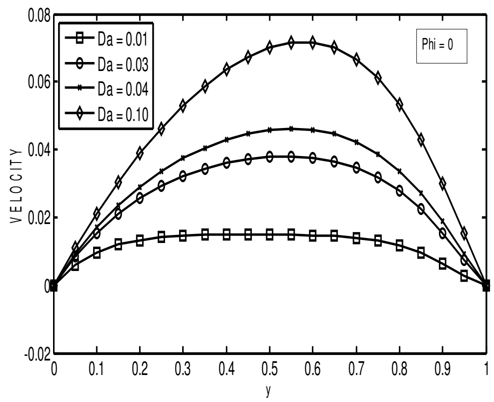


Fig - 23: Influence of Darcy number on the velocity profiles

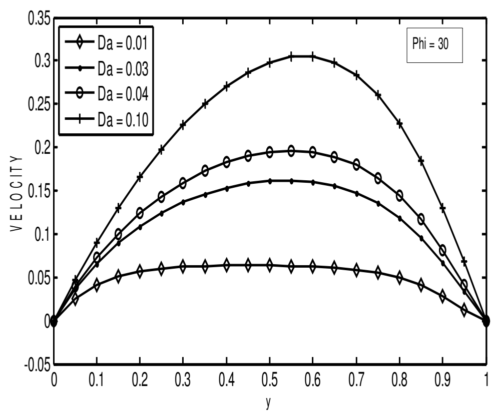


Fig - 24: Effect of Darcy Number on the velocity profiles

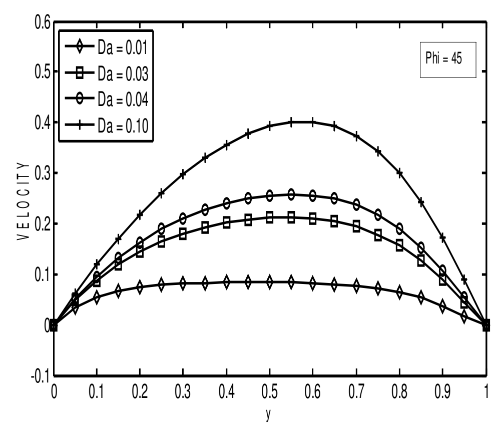


Fig - 25: Contribution of Darcy Number on the velocity profiles

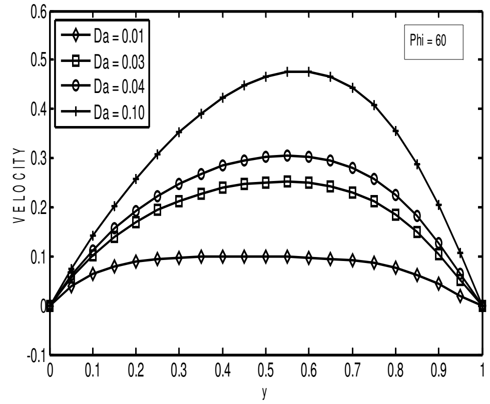


Fig - 26: Effect of Darcy Number on the velocity profiles

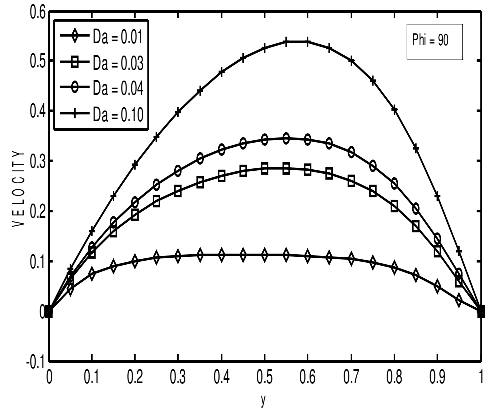


Fig - 27: Influence of Darcy Number on the velocity profiles

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