VARIABLE VISCOSITY AND NON-CONSTANT THERMAL CONDUCTIVITY OF A DUAL MIXED CONVECTION FLOWS THROUGH A POROUS MEDIUM

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Abstract

In this work, we examined variable viscosity and non-constant thermal conductivity of a dual mixed convection flows in a vertical channel through a porous medium.

We employed Galerkin weighted residual method to solve the resulting non-linear equations. The results show the effects of variable viscosity parameter, thermal conductivity parameter, Brinkman number, Reynolds number, Prandtl number and Darcy number on the flow system.

Keywords: Mixed convection, Weighted residual method, vertical channel and porous medium.

INTRODUCTION

Non-Newtonian fluids have received much attention than Newtonian fluids in the recent years due to its practical importance, rapid development of modern industrial materials and technological applications. The theoretical investigations on fully developed mixed convection in vertical or inclined ducts are often devoted to a description of the changes on the velocity profiles induced by buoyancy as well as to the determination of the conditions for the onset of flow reversal (crossover from a columnar to a cellular flow). Indeed, the flow reversal phenomenon arises when buoyancy forces are so strong that there exists a domain within the duct where the local fluid velocity has a direction opposite to the mean fluid flow. These studies are often based on the assumption that the effect of viscous dissipation in the fluid is negligible. This assumption holds whenever the fluid has sufficiently high thermal conductivity, a small Prandtl number and sufficiently high wall heat fluxes are present [6]. It has given insight in the understanding dynamics of terrestrial heat flow through aquifer, hot fluid and ignition front displacements in the reservoir engineering, flow of moisture through porous industrial materials, oil recovery, ceramic processing, catalytic reactors, polymer solution, molten plastics, preheating coal-water mixture, to mention but just a few applications.

Heat transfer problem of third grade fluids without heat source has been studied by several authors: Olajuwon [1] examined the flow and natural convection heat transfer in a power-law fluid past a vertical plate with heat generation. The fundamental importance of convective flow in porous media has been established in the recent books by Nield and Bejan [2], Ingham et al.[3] Bejan and Kraus [4]. The above studies of free and mixed convection flow in vertical channels are based on the hypothesis that the fluids are non-Newtonian. Moreover, because of their technological importance, studies involving free, forced and mixed convection flow of non-Newtonians in channels are very important in several industrial processes. Szeri and Rajagopal [5] examined the flow of a Non-Newtonian fluid between heated parallel plates. Barletta et al [6] considered dual mixed convection flows in a vertical channel. Ingham et al [7] studied combined free and forced convection in vertical channels of porous media. Habibis et al considered flow reversal of fully developed mixed convection in a vertical channel with chemical reaction. Motivated by the work of Barletta et al [6], we considered variable viscosity and non-constant thermal conductivity of a dual mixed convection flows in a vertical channel through a porous medium.

GOVERNING EQUATIONS

Following Barletta et al [6] the basic governing equations are as follows:

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$$\frac{d}{dy}\left(\mu(T)U'\right)-\frac{dp}{dx}+\rho g\beta\left(T-T_r\right)-\mu_{ef}\,\frac{u}{k}=0 \tag{1}$$

$$\frac{1}{\rho c_p}\frac{d}{dy}\left(K(T)T'\right)+\frac{\mu(T)}{\rho c_p}\left(U'\right)^2+\mu_{ef}\,\frac{u^2}{\rho c_p k}=0 \tag{2}$$

The appropriate initial and boundary condition are as follows

$$u(0)=0,u(L)=0,T(0)=T_r,T(L)=T_r \tag{3}$$

where θ -is the dimensionless temperature, k is the permeability of the porous media, K is the thermal conductivity, ρ is the density, C_p is the specific heat at constant pressure, μ is the dynamic viscosity, $\mu\left(\frac{\partial u}{\partial r}\right)^2$ is the viscous heating effect, direction, μ_{ef} is the effective viscosity, e^T is the thermal expansion, T_0 is the fluid initial temperature or wall temperature, T_r is the reference temperature, T is the absolute temperature within the boundary layer, T_1, T_2,.....T_∞ - Temperature at the plate, β is the coefficient of thermal expansion, p is the pressure, L is the channel half width, g is the acceleration due to gravity, u is the dimensionless velocity, y is the dimensionless transversal coordinate.

From Equations (1) and (2) we seek variable thermal conductivity and Reynolds model of the form

$$k(T)=k_0e^{-\alpha\theta},\mu(T)=\mu_0e^{-M\theta} \tag{4}$$

we introduce the following variables and parameters

$$y'=\frac{y}{lo},u=\frac{U}{U_m},\theta=\frac{T-T_r}{T_1-T_r},Da=\frac{k}{Ulo^2} \tag{5}$$

Substituting (4)&(5) into (1) & (2) and dropping the primes we obtain

$$\frac{d}{dy}\left(e^{-M\theta}u'\right)-c_1+Gr-\frac{u}{Da}=0 \tag{6}$$

$$\frac{1}{\Pr}\frac{d}{dy}\left(e^{-\alpha\theta}\theta'\right)+\frac{Br}{Pe}e^{-M\theta}\left(u'\right)^2+\frac{u^2}{Da}=0 \quad (7)$$

where

$$c_1=\frac{Clo^2}{\mu_0U_m},Gr=\frac{lo^2\rho g\beta\left(T_1-T_r\right)}{\mu_0U_m},\frac{Br}{Pe}=\frac{\mu_0U_mlo^2}{lo^2\rho c_p\left(T_1-T_r\right)lo},\Pr=\frac{lo\rho c_p\mu_{ef}}{k_0} \quad (8)$$

Following Habibis et al [8] the transformed boundary condition are as follows

$$u(0)=0,u(1)=0,\theta(0)=R_T,\theta(1)=-R_T \quad (9)$$

We proceed to solve equations (7) and (8) subject to (9) numerically using Galerkin-Weighted Residual Method as follows:

let $u=\sum_{i=0}^{2}A_ie^{y},\theta=\sum_{i=0}^{2}B_ie^{\left(-i/4\right)y}$ (10)

The results are presented in Figures 1-6

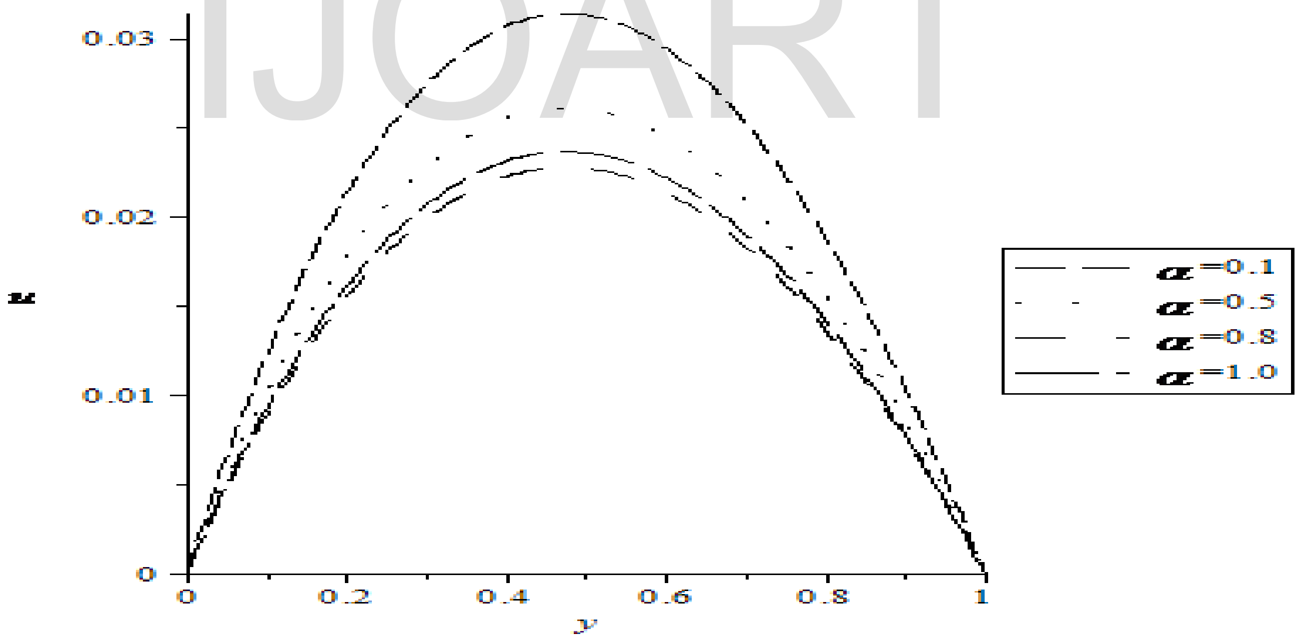

Figure1: Graph of the velocity function u for various values of $Br=0.5,\Pr=Gr=1.0$

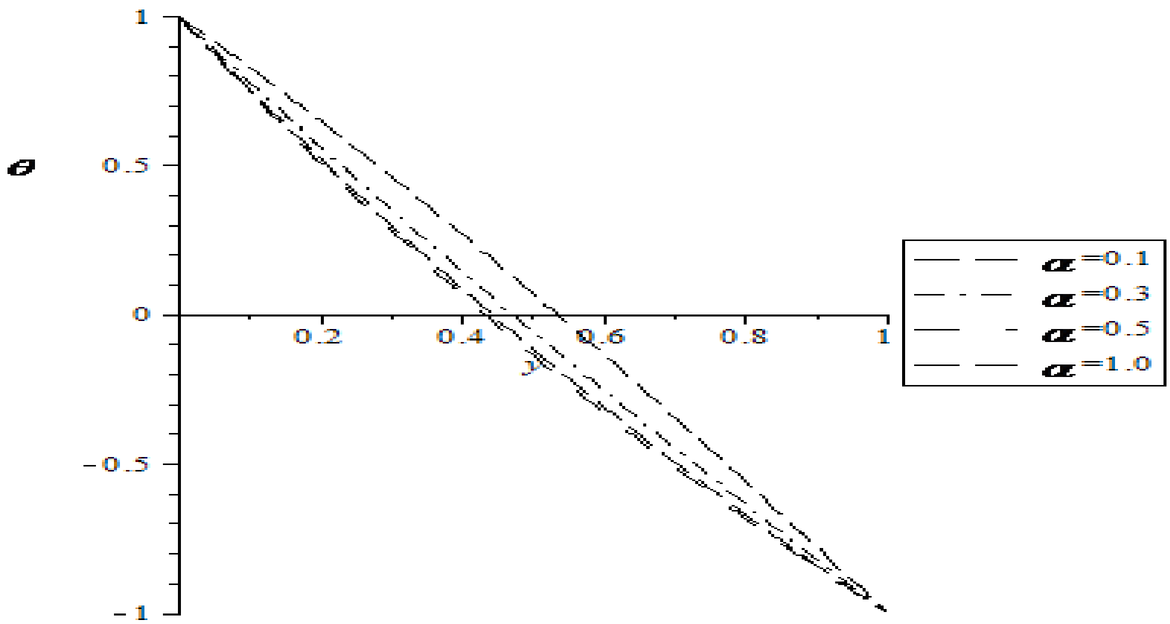

Figure 2: Graph of the temperature function θ for various values of $Br = \Pr = Gr = 1.0, Pe = 0.75$

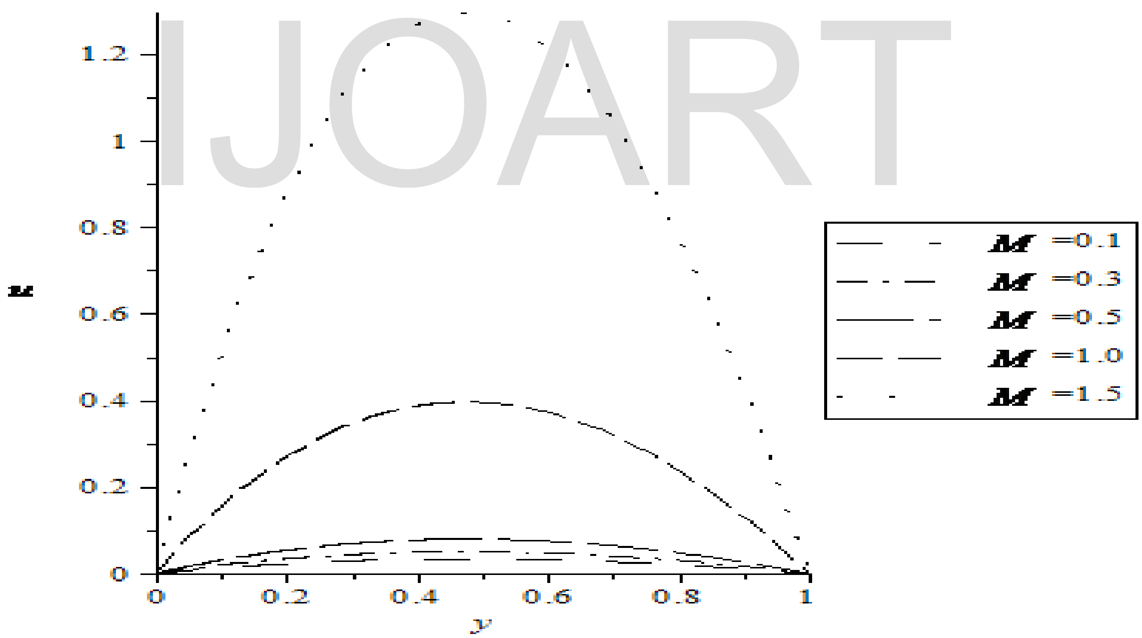

Figure3: Graph of the velocity function u for various values of $Br = 0.5, \Pr = Gr = 1.0$

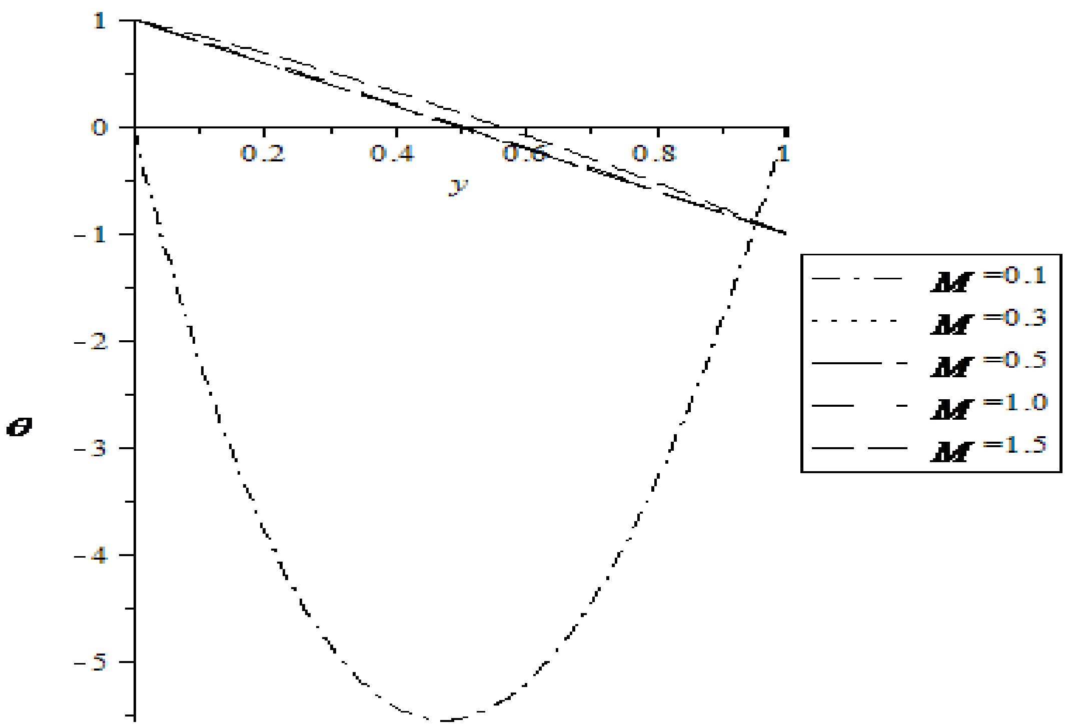

Figure 4: Graph of the temperature function θ for various values of $Br = \Pr = Gr = 1.0, Pe = 0.75$

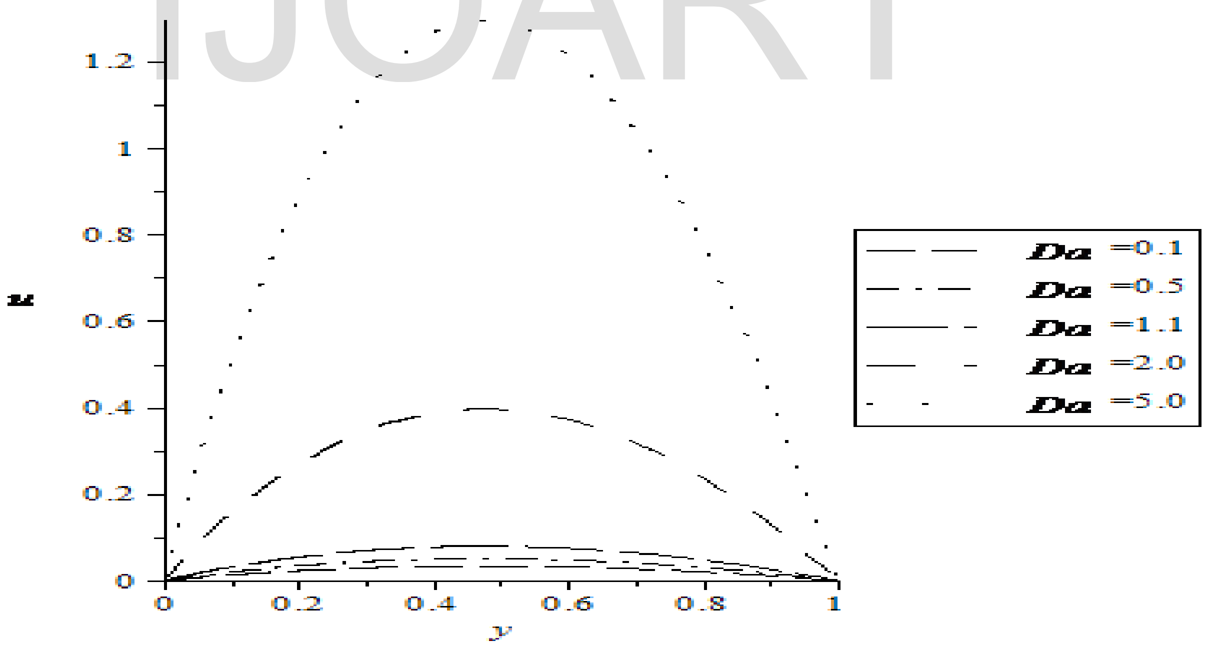

Figure5: Graph of the velocity function u for various values of $Br = 0.5, \Pr = Gr = 1.0$

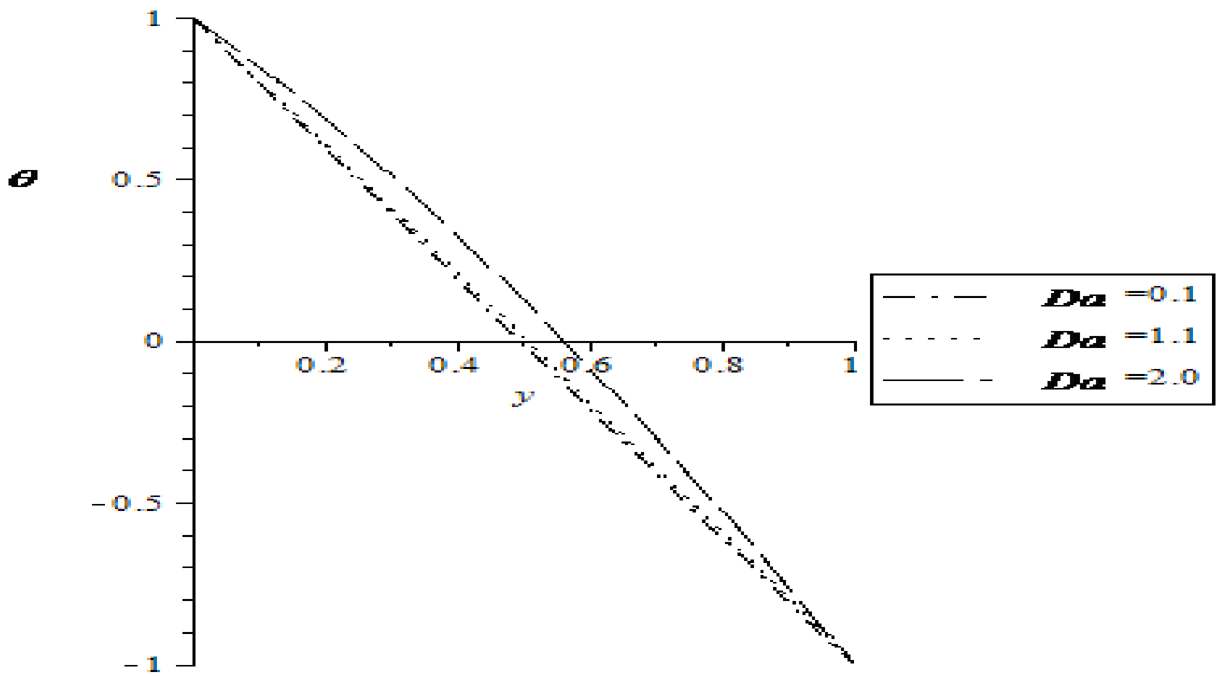

Figure 6: Graph of the temperature function θ for various values of $Br = \Pr = Gr = 1.0, Pe = 0.75$

Discussion of Results/Conclusion

From Figures1,3&5 the results show that the velocity field decreases as $Da, \mathrm{Re}, M, Gr, Br$ parameters, thermal conductivity parameter and variable viscosity increases .From Figures 2,4 &6 the result shows that the temperature field decreases with increase in each of $Pe, Br, \alpha, \Pr$ and M parameters increases. It is noticed that thermal conductivity parameter and variable viscosity parameter have a considerable effect on the flow.

Conclusion

It is observed that velocity field decreases as Darcy number and variable viscosity increases. The increase in thermal conductivity parameter and variable viscosity parameter lead to an increase fluid temperature. For engineering purpose, the results of this problem are of great interest in production processing, for the safety of life and proper handling of the materials during processing.

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