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Large Prandtl number effect on the velocity distribution field of free convective flow of two different types of immiscible fluids in a vertical channel, in Istanbul, Turkey, 2016

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Abstract: A free convective flow of two different types of immiscible fluids in a vertical channel which one is a micropolar fluid contained suspended fine particles in complex rotating motion and complex microstructure is considered in this paper. To achieve a good understanding of the complexity of this flow type a mathematical model with particular interface was developed in which dimensionless parameters such as the material parameter (K), the Prandtl number (Pr), the mixed convection parameter (GR), the magnetic parameter (Ha) and the Eckert number (Ec) appeared with some effects. Therefore, results are presented for dimensionless linear and microrotation velocity. Local skin friction coefficients for the two regions are also deduced.

Keywords: micropolar - viscous fluid, vertical channel, linear velocity, microrotation velocity, skin friction coefficient.

1 Introduction

A research on immiscible flows containing a Non-Newtonian micropolar fluid and a Newtonian viscous fluid is based on the work of Eringen theories [1- 2]. The micropolar fluid belongs to a specific class of the non-Newtonian fluid [3] and in the subclass of quasi- Newtonian. In practical use, many lubricants exhibit a complex rheological behavior because some additives are added.
In the last decades, magneto-hydrodynamics flow is largely considered by many researchers. The main reason is that the use of external magnetic has now become widespread for controlling the transport phenomena. Analytical and numerical studies were conducted with many types of fluids such viscoelastic fluids and nanofluids in mixed convection flows which represented a wide range of non-Newtonian fluids. K-L Hsiao [4-5] presented analytically the performance of a heat and mass transfer of a steady laminar boundary-layer flow of an electrically magnetic conducting viscoelastic fluid of second-grade. This fluid is subject to suction and to a transverse uniform magnetic and electric field past a semi-infinite stretching sheet. The dominance of the buoyant effect, magnetic effect, electric effect and mass transfer effect are elucidated. The Rivlin–Ericksen model for second-grade-viscoelastic fluid is used in the momentum equations to study the similar problem around a porous wedge [6]. Another related problem and dealing with the nanofluids including viscous dissipation is treated also by K-L Hsiao [7].
On the other hand, regarding other non-Newtonian fluid as micropolar fluids we can cite some studies. Singh & al. have presented a model describing the micropolar fluid film mechanism [8]. Some works are devoted to natural convection with these fluids [9]. In the present study, the interest

of magnetic field acting on a micropolar fluid is highly recognized. No considerable literature is found in this area; however, it is useful to cite pertinent and similar works with the present [10-12]. Ishak & al. [13] have studied the magnetohydrodynamic (MHD) convective and mixed flow, through a regular stopping point (stagnation point) of the flow on a vertical surface, immersed in an incompressible micropolar fluid. The study shows the existence of a region where the flow is reversed (the velocity changes a direction), they also found that studies on the convective flow of a micropolar and viscous fluid without the magnetic field influence, have failed to prove the existence of a transient flow regime. Other types of works are made on the free convective flows in the absence of magnetic field such as the study made by Chahoui & al. [14], the examination of the effects of microstructure and microrotation on the lubrication devices in the boundary layer, according to them, the effect of the particle size (dimensions of the particle with and the lubricant film thickness ratio) and the shear couple have an apparent effect on the flow disturbance and the equivalent viscosity of the micropolar fluid. J.P Kumar & al. [15], are studied analytically the fully developed free convective flow of micropolar and viscous fluids in vertical channel, they have observed that the parameter of the mixed convection has favored the velocity profiles, but no observation for the variation of the temperature profiles because the final energy differential equations depends only per the thermal conductivity and the channel width variation, while the material parameter doesn't favor the linear velocities which represent a disadvantage for lubrication systems. In works done on Non-Newtonian micropolar fluid flows under the magnetic field, the same model under magnetic field was investigated by N. Kumar and S. Gupta [16], in general, they have obtained the same results using the analytic solution way, we can also add the one of Kim [17] study, in which, the researcher has investigated the instability of convective flow of micropolar fluids through a vertical and movable flat plate in a porous medium. In there, Kim has found that the aspiration velocity rate through the porous media of a micropolar fluid decreases when the magnetic parameter increases, so that the aspiration velocity increases when the Grashof number increases. With the aim to study the influence of the effects of microstructure on the free convective flow of non-Newtonian fluids of micropolar type and in order to explain the problems caused by external forces and mixed convection of fluids in enclosed spaces, as in the instruments used in the systems of air conditioning, solar energy collection, the cooling systems of nuclear reactors [15,18], it was necessary to study the transport phenomena set involved in this type of fluid according to the variation of the physical parameters, mentioning among these parameters, the material parameter characterizing the structure and the form at the microscopic level of the suspended fine particles of micropolar fluids [1]. Other characteristics are the mixed convection parameter defined by the Grashof and Reynolds number ratio [19, 20], the magnetic parameter characterizing a linear, a surface and\or a volume of a magnetic field flow [14], Prandtl number which characterizes the viscous diffusivity rate and the thermal diffusivity ratio and finally the Eckert number which represents the kinetic energy and the enthalpy energy ratio [16, 21].

2 Problem Formulation and numerical approach

The suggested model theoretically and numerically studied, concerns a vertical channel, composed of two infinite isothermal parallel plates, negligible thickness in (*Ox*) axis direction, limited in (*Oy*) axis direction and maintained at different temperatures T_1^* and T_2^* where $T_1^* \geq T_2^*$, under ($B=\sigma^* B_0^2$) a constant magnetic field influence in (*Oy*) axis direction. Two immiscible fluids are moved in contact between them.

In general the two-dimensional Navier- Stokes equations of mass conservation, macro/micro-momentum and energy equations can be written in forms definite by Eringen for the Non-Newtonian micropolar fluid in the first region and in classical forms for the second region.

The Two-dimensional continuity equation.

$$\frac{\partial U_1}{\partial x}+\frac{\partial V_1}{\partial y}=0$$

The macro/micro-momentum equations.

$$U_1\frac{\partial U_1}{\partial x}+V_1\frac{\partial U_1}{\partial y}=-\frac{1}{\rho}\frac{\partial P}{\partial x}+\frac{1}{\rho_1}(\mu_1+\sigma)\left(\frac{\partial^2 U_1}{\partial x^2}+\frac{\partial U_1}{\partial y^2}\right)+g\beta_1\Delta T+\frac{\sigma}{\rho_1}\frac{\partial n}{\partial y}-\frac{\sigma^* B_0^2 U_1}{\rho_1}$$

$$U_1\frac{\partial V_1}{\partial x}+V_1\frac{\partial V_1}{\partial y}=-\frac{1}{\rho}\frac{\partial P}{\partial y}+\frac{1}{\rho_1}(\mu_1+\sigma)\left(\frac{\partial^2 V_1}{\partial x^2}+\frac{\partial^2 V_1}{\partial y^2}\right)-\frac{\sigma}{\rho_1}\frac{\partial n}{\partial x}$$

$$j.(U_1\frac{\partial n}{\partial x}+V_1\frac{\partial n}{\partial y})=-\frac{2\sigma n}{\rho_1}+\frac{\sigma}{\rho_1}\left(\frac{\partial V_1}{\partial x}-\frac{\partial U_1}{\partial y}\right)+\frac{\gamma}{\rho_1}\left(\frac{\partial^2 n}{\partial x^2}+\frac{\partial^2 n}{\partial y^2}\right)$$

The energy equation.

$$U_1\frac{\partial T_1}{\partial x}+V_1\frac{\partial T_1}{\partial y}=\frac{k_1}{\rho_1 C_{p1}}\left(\frac{\partial^2 T_1}{\partial x^2}+\frac{\partial^2 T_1}{\partial y^2}\right)+\frac{\sigma^* B_0^2 U_1^2}{\rho_1 C_{p1}}$$

Where the spin-gradient viscosity γ and the micro-inertia density j are linked usually by: $\gamma=\left(\mu_1+\frac{\sigma}{2}\right).j$ and $j=h_1^2$ in the present study. n represents the microrotation velocity, which is the normal vector on (xOy) plane, the component g represents respectively the gravity acceleration.

In the second region of the viscous fluid the Navier- Stokes equations can be written only in macroscopic scale.

The continuity equation.

$$\frac{\partial U_2}{\partial x}+\frac{\partial V_2}{\partial y}=0$$

The macro/micro-momentum equations.

$$U_2\frac{\partial U_2}{\partial x}+V_2\frac{\partial U_2}{\partial y}=-\frac{1}{\rho}\frac{\partial P}{\partial x}+\frac{\mu_2}{\rho_2}\left(\frac{\partial^2 U_2}{\partial x^2}+\frac{\partial U_2}{\partial y^2}\right)+g\beta_2\Delta T-\frac{\sigma^* B_0^2 U_2}{\rho_2}$$

$$U_2\frac{\partial V_2}{\partial x}+V_2\frac{\partial V_2}{\partial y}=-\frac{1}{\rho}\frac{\partial P}{\partial y}+\frac{\mu_2}{\rho_2}\left(\frac{\partial^2 V_2}{\partial x^2}+\frac{\partial^2 V_2}{\partial y^2}\right)$$

The energy equation.

$$U_2\frac{\partial T_2}{\partial x}+V_2\frac{\partial T_2}{\partial y}=\frac{k_2}{\rho_2 C_{p2}}\left(\frac{\partial^2 T_2}{\partial x^2}+\frac{\partial^2 T_2}{\partial y^2}\right)+\frac{\sigma^* B_0^2 U_2^2}{\rho_2 C_{p2}}$$

The next step of work consists to eliminate all dimensions of variables and constant parameters in the differential equations.

Non-Newtonian micropolar/Newtonian viscous fluid

Making changes of the following variables

$$y = Y\,h_1\,;\ U_1 = U_0.f(Y)\ ;\ (T_1 - T_1^*) = (T_1^* - T_2^*)\ \theta_1\ or\ T_1 = \Delta T\,\theta_1 + T_1^*\,;\ n = \frac{U_0}{h_1}N,(first-region)$$

$$y = Y\,h_2\ ;\ U_2 = U_0.g(Y);(T_2 - T_2^*) = (T_1^* - T_2^*)\ \theta_2\ or\ T_2 = \Delta T\,\theta_2 + T_2^*,(second-region)$$

Further the numerical study will be limited by the interval [-1; 1], and the specific method used here is namely the multipoint boundary value problem. Two separate systems of equations developed above are linked by a third point and pertinent transformation, accomplished by defining a new common variable for the both regions, is introduced to take into account that only two points should be used, an example of results in figure 1, 2 and 3. Dimensionless equations for non-Newtonian micropolar fluid and Newtonian viscous fluid obtained and used are:

$$f'' - K_1.Ha.f + K_2.N - K_1.GR.\theta_1 = 0\,;$$
$$N'' - 2K_3N - K_3f' = 0 \quad ;$$
$$\theta_1'' + Br.Ha.f^2 = 0$$
$$g_2'' - Ha.\frac{\mu^*.}{H^2}.g + \frac{\mu^*.}{\rho^*.\beta^*H^2}.\frac{Gr}{\mathrm{Re}}\theta_2 = 0 \quad ;$$
$$\theta_2'' + \frac{k^*}{H^2}Br.Ha.g^2 = 0$$

The boundary conditions take the form

$$f(-1) = 0; \theta_1(-1) = 0\,; N(-1) = 0;\ g(1) = 0; \theta_2(1) = 0;\ f(0) = g(0); N\,'(0) = 0; \theta_1(0) = \theta_2(0) - 1;$$

$$f'(0) = (\frac{H}{\mu^*}g'(0) - K.N)/(K+1)\ ;\ \ \theta_1'(0) = \frac{H}{k^*}\theta_2'(0)$$

3 Results

Some results are visualized here according to the variations of Pr.

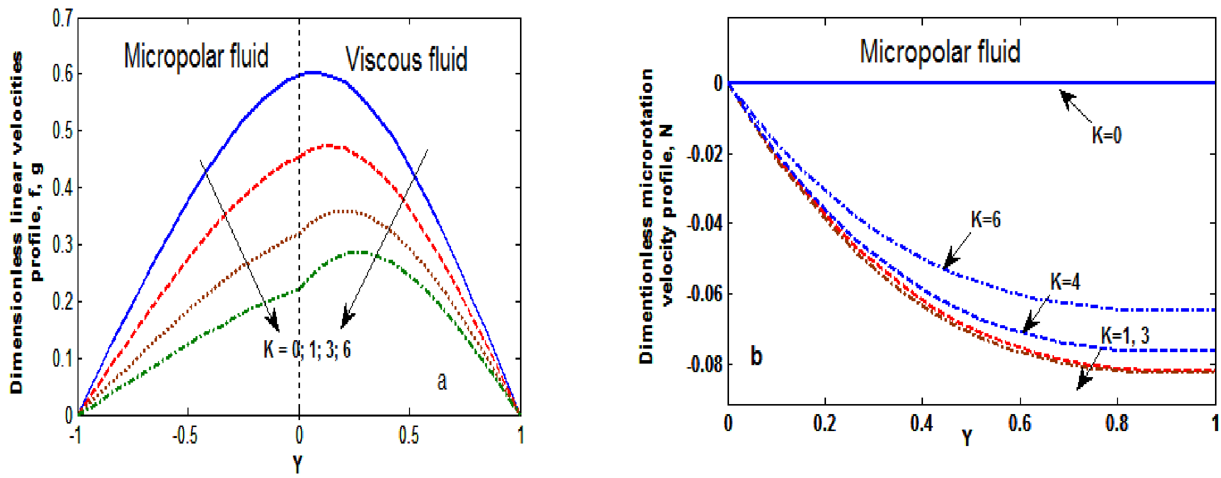

Figure 1. A linear velocity profiles (a), microrotation velocity profiles (b), according to a material parameter variation with « Ha=1, Ec=1, Pr=0.7, GR=5, H=1, k*=1, μ*=1, β*=1, ρ*=1».

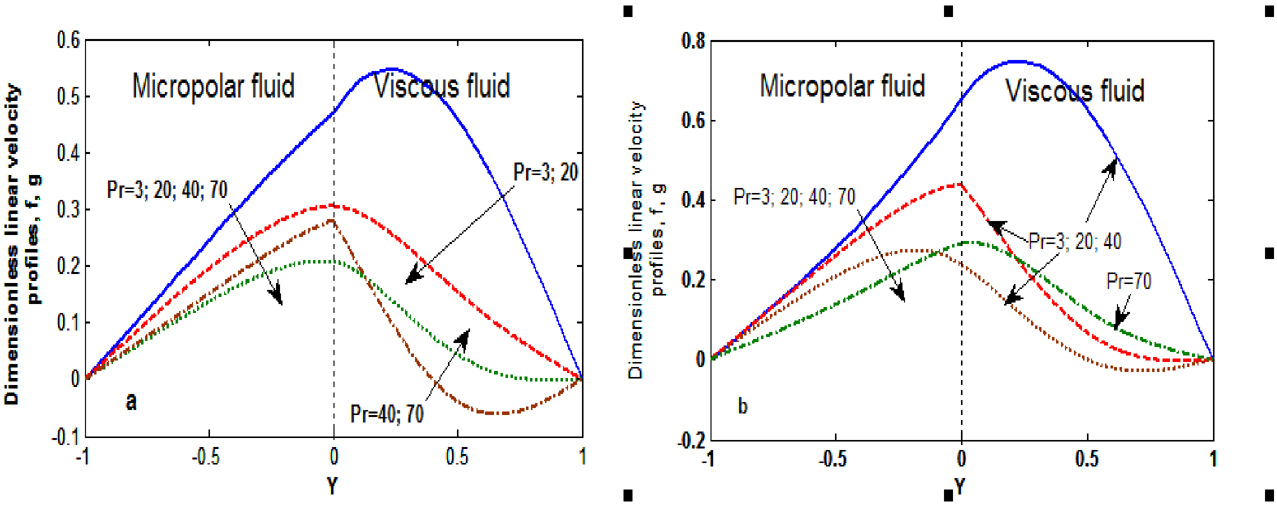

Figure 2. Decrease in the linear velocity profiles (a) for K=1 and (b) K→ 0 according to the Prandtl number variation from 3 to 70

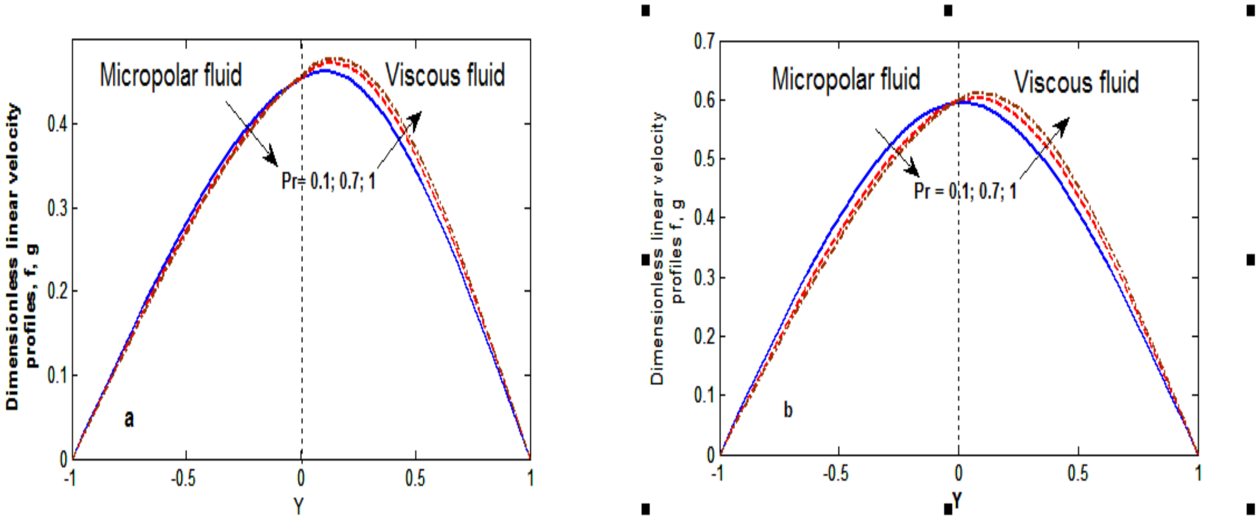

Figure 3. A linear velocity profiles for the case K=1 **(**a), linear velocity profiles for K→0 (b) according to Prandtl number variation from 0.1 to 1 with « Ha=1, Ec=1, GR=5, H=1, k*=1, μ*=1, β*=1, ρ*=1»

4 Conclusion

Following the results achieved by the numerical analysis of the proposed physical model, this consists of a single system formed of two regions loaded with immiscible fluids. Prandtl number from 40 to 70 inhibit the microrotation velocities but the material parameter from the value K→0 to 3, the Prandtl number up to 10 and the Eckert number from 0.0 to 0.6, favor the microrotation velocities.

We can also conclude that all the parameters involved in this study have a strong effect on the reduced velocities with the exception naturally of the mix convection parameter. It is convenient to have at the handsome tools to control the flow. Any decrease of the buoyancy forces represents an inconvenience for the lubricant systems.

A need of the non-Newtonian micropolar fluid is accompanied by higher skin friction, but the system can be controlled by a magnetic field to reduce it.

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