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DIFFUSSION-THERMO AND CHEMICAL REACTION EFFECTS ON AN UNSTEADY MHD FREE CONVECTION FLOW IN A MICROPOLAR FLUID

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Abstract. This paper considers a boundary layer analysis on the effects of diffusion-thermo, heat absorption and homogeneous chemical reaction on magnetohydrodynamic flow of an incompressible, laminar chemically reacting micropolar fluid past a semi-infinite vertical porous plate is made numerically. The governing partial differential equations are solved numerically using the finite element method. The numerical results are compared and found to be in good agreement with previous results as special case of the present investigation. The effects of the various important parameters entering into the problem on the velocity, microrotation, temperature and concentration fields within the boundary layer are discussed and explained graphically. Also the effects of the pertinent parameters on the local Skin friction coefficient, wall Couple stress and rates of heat and mass transfer in terms of the local Nusselt and Sherwood numbers are presented numerically in tabular form.

1. Introduction

For the last few decades, the dynamics of micropolar fluid is recognised as the field of active research, because this class of fluid represents mathematically and industrially in many applications such as body fluids, polymers, suspension fluids etc. Micropolar fluid is defined as fluid consisting of rigid, randomly oriented molecules suspended in a viscous medium which undergo translational as well as rotational motions. Eringen [1] theory has provided a good mathematical model for studying a number of complicated fluids. An extensive case study on the subject of micropolar fluid mechanics and its applications was given by Kim and Lee [2], Lukaswiascz [3] and Chamkha et al [4].

When the heat and mass transfer occurs simultaneously in a moving fluid, the relation between the fluxes and driving potentials are important in many practical and engineering applications. Also it has been found that an energy flux can be generated not only by temperature gradient but by composition gradient as

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well. The energy caused by a composition gradient is called the Dufour or the Diffusion-thermo effect. The energy caused by temperature gradient is called Soret or Thermal-diffusion effect. Generally, the Diffusion-thermo effects are of smaller order magnitude than the effects prescribed by Fourier's or Fick's laws and are often neglected in heat and mass transfer process. However, recently in a special case, the Dafour effect was found to be of order of considerable magnitude as it cannot be neglected, so it is considered in our present study, whichwas analyzed in the edition by Eckert and Drake [5]. The term Dufour effect referred to the heat flux produced by a concentration gradient. Convection heat and mass transfer in hydromagnetic flow of second grade fluid past a semi-infinite stretching sheet in the presence of thermal radiation and thermal diffusion and unsteady free convection heat and mass transfer in an MHD micropolar fluid in the presence of diffusion-thermo and thermal radiation was examined by Olajuwon [6, 7].

All industrial chemical processes are designed to transform cheaper raw materials to high value products (usually via chemical reactions). A "reactor", in which such chemical transformations take place, has to carry out several functions like bringing reactants into intimate contacts, providing an appropriate environment (temperature and concentration fields) at adequate time, and allowing for the removal of products. Fluid dynamics plays a vital role in establishing the relationship between the reactor hardware and the reactor performance. For a specific chemistry/catalyst, the reactor performance is a complex function of the underlying transport processes. The first step in any reaction engineering analysis is to formulate a mathematical framework to describe the rate (and mechanisms) by which one chemical species is transformed into another in the absence of any transport limitations (chemical kinetics). Once the intrinsic kinetic is available, the production rate and composition of the products are related, in principle, to react the volume, the configuration, and the mode of operation by solving the mass, momentum, and energy balances over the reactor. This is the central task of a reaction and reactor engineering activity. The analysis of the transport processes and interactions with chemical reactions are quite difficult. It is intimately connected to the underlying fluid dynamics. Such a combined analysis of chemical and physical processes constitutes for the core of the chemical reaction engineering. Fluid mechanics played a special role in this work by incompressible viscous flow. The aim of this logical statement is to furnish some result in different areas of aeronautics, hydraulics, heat and mass transfer etc. Fluid mechanics is involved nearly all areas of civil, mechanical, chemical, biotech engineering either directly or indirectly some example of direct involvement are those were we are considered with manipulating field: Sea and river defenses, Water distribution/sewage network, Hydraulic design of water/sewage treatment work, Dams irrigation, turbine and water retaining structure, Siphon, air foils, pumps, drafts. Recent advances in understanding the physics of flows and modeling the computational flow make tremendous contributions in chemical engineering. Rao and Sivaiah [8] have studied chemical reaction effects on unsteady MHD flow past semi-infinite vertical porous plate with viscous dissipation. Sivaiah and Srinivasa Raju [9] analyzed finite element solution of heat and mass transfer flow with Hall current, heat source, and viscous dissipation.

Muthucumaraswamy [10] presented the heat and mass transfer effects on a continuously moving isothermal vertical surface with the uniform suction by taking into account the homogeneous chemical reaction of the first order. Muthucumaraswamy and Meenakshisundaram [11] investigated a theoretical study of the chemical reaction effects on a vertical oscillating plate with variable temperature and mass diffusion. Das [12] have estimated the effect of chemical reaction and thermal radiation on heat and mass transfer flow of MHD micropolar fluid in a rotating frame of reference. Sivaiah and Anand Rao [13] analyzed chemical reaction effects on an unsteady MHD free convective flow past and infinite vertical porous plate with constant suction and heat source. Chamkha et al [14] reported unsteady MHD natural convection from a heated vertical porous plate in micro polar fluid with joule heating, chemical reaction and radiation effects. Sivaiah and Anand Rao [15] they investigated chemical reaction effects of an unsteady MHD free convective flow past a vertical porous plate in the presence of suction or injection. Bakr [16] examined an analysis on MHD free convection and mass transfer adjacent to moving vertical plate for micro polar fluid in a rotating frame of reference in presence of heat generation/absorption and a chemical reaction. Das [17] analyzed the effects of chemical reaction and thermal radiation on heat and mass transfer flow of MHD micro polar fluid in a rotating frame of reference. Damesh et al [18] they estimated combined effect of heat generation or absorption and first order chemical reaction to micro polar fluids flow over a uniform stretched surface.

Motivated by the above mentioned work, the goal of this study is to investigate numerically the effects of diffusion-thermo, heat absorption and homogeneous chemical reaction on the free convective flow of micropolar fluid through a semi-infinite vertical plate. Using non-dimensional variables, the governing equations are transformed into system of non-linear partial differential equations that have been solved numerically using the finite element method. Numerical calculations have been carried out for different values of the physical parameters controlling the fluid dynamics in the flow regime which are presented graphically. The skin friction, wall couple stress, Nusselt number and Sherwood number have also been computed and are shown in tabular form.

2. Mathematical formulation

Consider a laminar boundary layer flow of an incompressible, electrically conducting Micropolar fluid past a semi-infinite moving vertical permeable plate embedded in a uniform porous medium and subjected to a constant manetic feild B_0 under the influence of diffusion-thermo, heat absorption and homogeneous chemical reaction effects were analyzed. The flow is assumed to be in the x^*-direction which is taken along the plate in the upward direction and y^*-axis is normal to it. The surface of the plate is held at a constant heat flux q_w and mass flux m_w due to the semi-infinite plane surface assumption, the flow variables are functions of z^* and t^* only. It is assumed that induced magnetic field, the outward electric field and the electric field due to the polarization of chargers are negligible. Since with the assumption that the plate has an oscillatory movement on time t^* and frequency n^* with velocity $u^*(0, t^*)$ which is given by $u^* = U_r(1 + \varepsilon \cos nt)$, where U_r is uniform velocity and ε is small constant. Also it is assumed that the whole system rotate with a constant frame Ω in micropolar fluid about y^*-axis. It is assumed that the plate is infinite in extent and hence all physical quantities depends on y^* and t^* only.

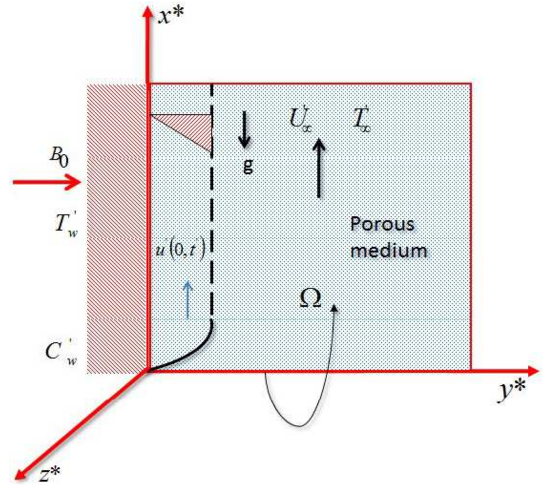

FIGURE 1. Schematic diagram of Physical model.

The governing equations that describe the physical situation can be written as

$$\frac{\partial w^*}{\partial y^*} = 0 \tag{2.1}$$

$$\frac{\partial u^*}{\partial y^*} + w^*\frac{\partial u^*}{\partial y^*} - 2\Omega v^* = (\nu + \nu_r)\frac{\partial^2 u^*}{\partial y^{*2}} + g^*\beta_T(T_w - T_\infty) + g^*\beta_C(C_w - C_\infty) - \frac{\nu u^*}{k} - \frac{\sigma B_0^2 u^*}{\rho} - \nu_r\frac{\partial \bar{\omega}_2^*}{\partial y} \tag{2.2}$$

$$\frac{\partial v^*}{\partial t^*} + w^*\frac{\partial v^*}{\partial y^*} + 2\Omega u^* = (\nu + \nu_r)\frac{\partial^2 v^*}{\partial y^{*2}} - \frac{\nu v^*}{k} - \frac{\sigma B_0^2 v^*}{\rho} + \nu_r\frac{\partial \bar{\omega}_1^*}{\partial y^*} \tag{2.3}$$

$$\rho j\Big(\frac{\partial \bar{\omega}_1^*}{\partial t^*} + w^*\frac{\partial \bar{\omega}_1^*}{\partial y^*}\Big) = \Lambda\frac{\partial^2 \bar{\omega}_1^*}{\partial y^{*2}} \tag{2.4}$$

$$\rho j\Big(\frac{\partial \bar{\omega}_2^*}{\partial t^*} + w^*\frac{\partial \bar{\omega}_2^*}{\partial y^*}\Big) = \Lambda\frac{\partial^2 \bar{\omega}_2^*}{\partial y^{*2}} \tag{2.5}$$

$$\frac{\partial T}{\partial t^*} + w^*\frac{\partial T}{\partial y^*} = \frac{\kappa}{\rho C_p}\frac{\partial^2 T}{\partial y^{*2}} - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial y^*} - \frac{Q_0}{\rho C_p}(T_w - T_\infty) + \frac{DK_T}{\rho C_p}\frac{\partial^2 C}{\partial y^{*2}} \tag{2.6}$$

$$\frac{\partial C}{\partial t^*} + w^*\frac{\partial C}{\partial y^*} = D\frac{\partial^2 C}{\partial y^{*2}} - K_r'(C_w - C_\infty) \tag{2.7}$$

The appropriate boundary conditions are given by

$$(2.8)\quad \begin{cases} u^* = v^* = 0, \quad \bar{\omega}_1^* = \bar{\omega}_2^* = 0, \quad T = T_\infty, \quad C = C_\infty, & \text{for } t^* \leqslant 0 \\ u^* = U_r\big[1 + \frac{\varepsilon}{2}(e^{in^*t^*} + e^{-in^*t^*})\big], \quad v^* = 0, \quad \bar{\omega}_1^* = -\frac{i}{2}\frac{\partial v^*}{\partial y^*}, & \\ \bar{\omega}_2^* = -\frac{i}{2}\frac{\partial u^*}{\partial y^*}, \quad -k\frac{\partial T}{\partial y^*} = q_w, \quad -D\frac{\partial C}{\partial y^*} = m_w & \text{at } y^* > 0 \\ u^* = v^* = 0,\ \bar{\omega}_1^* = \bar{\omega}_2^* = 0,\ T = T_\infty,\ \ C = C_\infty,\ \text{ as } y^* \to \infty & \text{for } t^* > 0 \end{cases}$$

where u^*, v^* and w^* are velocity components along x^*, y^* and z^*-axis respectively. $\bar{\omega}_1^*$ and $\bar{\omega}_2^*$ are microrotation components along x^* and y^* components respectively. β_T and β_C are coefficient of thermal expansion and concentration expansion. ρ is the density of micropolar fluid, ν is the kinematic viscosity, ν_r is the kinematic microrotation viscosity, K is permeability of porous medium, σ is the electrical conductivity of the micropolar fluid, Λ is the spin gradient velocity, j is the micro inertia density, g^* is the acceleration due to gravity, T, T_∞ are temperature of fluid at boundary layer and far away from surface. k is thermal conductivity of the medium. C_p is specific heat at constant pressure p, q_r is the heat flux, C, C_∞ are concentration of the solute and far away from surface. D is the molecular diffusivity, c is concentration susceptibility. K_T is the thermo diffusion ratio and K_r' is the first order chemical reaction parameter. U_r is the uniform reference velocity and ε is small quantity constant.

The oscillatory plate velocity assumed in Eq. (2.8) is based on suggestion proposed by Ganapathy [19], we consider a convenient solution of continuity equation (2.1) to be

$$w^* = -w_0$$

where w_0 is the normal velocity at the plate for suction $w_0 > 0$, for blowing $w_0 < 0$. The radiative heat flux term is given by

$$(2.9)\qquad q_r = \frac{-4\bar{\sigma}}{3\bar{k}}\Big(\frac{\partial T^4}{\partial y^*}\Big)$$

Here $\bar{\sigma}$ is Stefan Boltzmann constant and $\bar{k}$ is mean absorption coefficient. Using Taylor's series expansion T^4 can be written as

$$(2.10)\qquad T^4 \cong 4T_\infty^3 T - 3T_\infty^4.$$

Now differentiating (2.10) w.r.t y^* using (2.11), we get

$$(2.11)\qquad \frac{\partial q_r}{\partial y^*} = \Big(\frac{16T_\infty^3\bar{\sigma}}{3\bar{k}}\Big)\frac{\partial^2 T}{\partial y^{*2}}$$

Introducing the following non-dimensional variable

$$(2.12)\qquad \begin{aligned} &u^* = \frac{u}{U_r}, \quad v^* = \frac{v}{U_r}, \quad y^* = \frac{yU_r}{v}, \quad n^* = \frac{nv}{U_r^2}, \quad \bar{\omega}_1^* = \frac{\bar{\omega}_1 v}{U_r^2}, \\ &\bar{\omega}_2^* = \frac{\bar{\omega}_2 v}{U_r^2}, \quad \theta = \frac{k}{q_w}(T - T_\infty), \quad \phi = \frac{D}{m_w}(C - C_\infty) \end{aligned}$$

Substituting equation (2.12) into equation (2.2) to (2.7) and dropping primes yield the following dimensionless equations:

$$(2.13)\qquad \frac{\partial u}{\partial t} - S\frac{\partial u}{\partial y} - Rv = (1+\lambda)\frac{\partial^2 u}{\partial y^2} + \mathrm{Gr}\,\theta + \mathrm{Gm}\,\phi - \Big(M^2 + \frac{1}{K}\Big)u - \lambda\frac{\partial \bar{\omega}_2}{\partial y}$$

$$\frac{\partial v}{\partial t} - S\frac{\partial v}{\partial y} + Ru = (1+\lambda)\frac{\partial^2 v}{\partial y^2} - \Big(M^2 + \frac{1}{K}\Big)v + \lambda\frac{\partial \bar{\omega}_1}{\partial y} \tag{2.14}$$

$$\frac{\partial \bar{\omega}_1}{\partial t} - S\frac{\partial \bar{\omega}_1}{\partial y} = \Delta\frac{\partial^2 \bar{\omega}_1}{\partial y^2} \tag{2.15}$$

$$\frac{\partial \bar{\omega}_2}{\partial t} - S\frac{\partial \bar{\omega}_2}{\partial y} = \Delta\frac{\partial^2 \bar{\omega}_2}{\partial y^2} \tag{2.16}$$

$$\frac{\partial \theta}{\partial t} - S\frac{\partial \theta}{\partial y} = \frac{1}{\mathrm{Pr}}\Big(1 + \frac{4F}{3}\Big)\frac{\partial^2 \theta}{\partial y^2} - \frac{Q\theta}{\mathrm{Pr}} + \mathrm{Df}\left(\frac{\partial^2 \phi}{\partial y^2}\right) \tag{2.17}$$

$$\frac{\partial \phi}{\partial t} - S\frac{\partial \phi}{\partial y} = \frac{1}{\mathrm{Sc}}\frac{\partial^2 \phi}{\partial y^2} - \mathrm{Kr}\,\phi \tag{2.18}$$

where $R = \frac{2\Omega v}{U_r^2}$ is the rotational parameter, $M = \frac{B_0}{Ur}\sqrt{\frac{\sigma v}{\rho}}$ is the rotational parameter, $\mathrm{Pr} = \frac{\mu\rho C_p}{k}$, $\mathrm{Sc} = \frac{v}{D}$, $\mathrm{Gr} = \frac{vg^*\beta_T q_w}{kU_r^3}$, $\mathrm{Gm} = \frac{vg^*\beta_C m_w}{DU_r^3}$ are Prandtl number, Schmidt number, Grashof and modified Grashof number respectively. $F = \frac{4T_\infty^3\bar{\sigma}}{kk}$ is the radiation parameter, $K = \frac{kU_r^2}{v^2}$ is the radiation parameter, $Q = \frac{Q_0 v^2}{U_r^2 k}$ is heat absorption parameter, $\mathrm{Df} = \frac{DK_T m_w}{\rho C_p q_w}$ is the Dufour number, $S = \frac{w_0}{U_r}$ is the suction parameter, Homogeneous chemical reaction parameter $Kr = \frac{K'rv}{U_r^2}$, $\Delta = \frac{\Lambda}{uj}$ is the dimensionless material parameter and viscosity ratio parameter $\lambda = \frac{\nu_r}{v}$.

The boundary conditions become:

$$\begin{cases} u = v = 0, \quad \bar{\omega}_1 = \bar{\omega}_2 = 0, \quad \theta = 0, \quad \phi = 0, & \text{for } t \leqslant 0 \\ u = \big[1 + \frac{\varepsilon}{2}(e^{int} + e^{-int})\big], \quad v = 0, \quad \bar{\omega}_1 = -\frac{1}{2}\frac{\partial v}{\partial y}, \quad \bar{\omega}_2 = \frac{1}{2}\frac{\partial u}{\partial y} & \\ \theta' = -1, \quad \phi' = -1, & \text{at } y = 0 \\ u = v = 0, \quad \bar{\omega}_1 = \bar{\omega}_2 = 0, \quad \theta = \phi = 0, \qquad \text{as } y \to \infty & \text{for } t > 0. \end{cases} \tag{2.19}$$

3. Method of problem solution

The governing equations (2.13) to (2.18) subject to the boundary conditions (2.19) have been solved numerically using the Finite element method discussed in Bathe [20] and Reddy [21] Chung [22] and Connor and Brebbia [23] has been utilized in diverse branches of applied mechanics and fluid dynamics including combustion, geomechanics, magnetohydrodynamics and many other areas of research technology. The basic steps involved in the finite-element analysis of a problem are as follows:

The method has the following five main steps:

(1) Discretization of the domain,
(2) Derivation of the element equations,
(3) Assembly of elements,
(4) Impositions of boundary conditions,
(5) Solution of the assembled Equations.

The physical quantities of primary interest are the Skin-friction, Wall couple stress, Nusselt number and Sherwood number are given by following:

$$c_f = \left(\frac{\partial u}{\partial y}\right)_{y=0}, \quad C_w = -\left(\frac{\partial w}{\partial y}\right)_{y=0}, \quad \mathrm{Nu} = \left(\frac{\partial \theta}{\partial y}\right)_{y=0}, \quad \mathrm{Sh} = \left(\frac{\partial \phi}{\partial y}\right)_{y=0}.$$

4. Validation of Numerical results

To verify the accuracy and validity of the numerical results employed by weighted residual approach, Galerkin finite element method in the present analysis. The results have been compared to the local skin friction coefficient C_f, wall couple stress coefficient C_w, Nusselt number Nu and Sherwood number Sh with those results reported analytically by Olajuwon [7] for distinct values of F, S, Df, and R are presented quantitatively in Tables 1 to 4 in the absence of Heat absorption and homogeneous chemical reaction. It is observed from these tables that excellent agreement between the results exists. Therefore these favorable comparisons lend an immense confidence in the results reported consequently. Table 1 depicts the effect of Nr, S, Df, and R on the skin friction coefficient C_f. It is observed that as increasing Nr, Df, and R the local skin friction coefficient increases, whereas skin friction coefficient decreases on increasing S. Table 2 shows the effect of Nr, S, Df, and R on couple stress coefficient C_w. It is observed that as increasing Nr, S, and Df on Nusselt number Nu. It is found that as increasing Nr and Df the Nusselt number decreases while it increases as S increases. Table 4 portrays the effect of S on Sherwood number Sh. It is found that as increasing the Sherwood number Sh increases.

5. Grid Independency Test

A grid refinement test is carried out by dividing the whole domain into successively sized grids 81×81, 101×101 and 121×121 in the z-axis direction. Furthermore we ran the developed code for different grid sizes and finally we found that all the solutions are independent of grid. After many tests we adopted grid size as 101 intervals. Thus all the computations were carried out with 101 intervals of equal step size 0.01. At each node 6 functions are to be evaluated and after assembly of element equations, a set of 606 non-linear equations are obtained and which may not produce closed form solutions, consequently an iterative scheme is adopted to solve the system by introducing the boundary conditions. Finally the solution is assumed to be convergent whenever the relative difference between two successive iterations is less than the value 10^{-6}.

6. Results and discussions

The formulation of the diffusion-thermo, heat absorption and homogeneous chemical reaction effects on an unsteady magnetohydrodynamic free convection flow in a micropolar fluid was accomplished out in the preceding sections and a representative set of results is reported graphically in Figures 2 to 19. These results are obtained to illustrate the influence of various parameters on translation velocity V, micro-rotation ω, temperature θ, and concentration ϕ profiles. In present study we adopted the following default parameter values of finite element computations:

$nt = \pi/2$, $\lambda = 0.2$, $K = 0.5$, $\mathrm{Gr} = 10$, $\mathrm{Gm} = 5$, $M = 10$, $R = 0.2$, $S = 1$, $\mathrm{Pr} = 0.71$, $\mathrm{Sc} = 0.6$, $F = 0.1$, $Q = 10$, $\mathrm{Df} = 0.02$, $\mathrm{Kr} = 0.1$. All graphs therefore correspond to these values unless specifically indicated on the appropriate graph. The permeability in all the figures plotted is set at 0.5 which corresponds to a highly porous regime. The value of Pr is taken to be 0.71 which corresponds to air at 20°C and 1 atmospheric Pressure and the value of Sc is 0.6 (water-vapor). Due to convection problem positive large values of $\mathrm{Gr} = 10$ and $\mathrm{Gm} = 5$ are chosen.

The effect of a micro polar fluid viscosity ratio parameter λ on the translation velocity profiles is presented in the Figure 2 in general, the linear velocity of the fluid for Newtonian fluid ($\lambda = 0$) is higher than that of non-Newtonian micro polar fluid. It shows that the translation velocity field decreases as the increasing values of viscosity ratio parameter λ. In case of Figure 3 micro rotation profiles also decreases as increase of λ.

The variation of non-dimensional velocity, Microrotation for different values of M is illustrated in Figures 4 and 5. It is observed that from Figure 4 velocity increases as magnetic parameter increases. From Figure 5, it is clear that the microrotation component decreases near the plate. As explained above, application of a uniform magnetic field normal to the fluid flow direction gives rise to a resistive force. This force is called Lorentz force which tends to slow down the movement of the electrically conducting fluid in the vertical direction. Also higher the Lorentz forces smaller the axial velocity in the flow region.

Figures 6 and 7 depicts the translational velocity and microrotation profiles for various values of heat absorption parameter Q. Both translation velocity and microrotation distribution decreases with increase of Q. Heat sink physically implies absorption of heat from the surface.

Figures 8 and 9 present the behavior of translation velocity and micro rotation ω profiles for various values of rotational parameter R. It is observed that an increasing in rotational parameter leads to decreasing in the values of translational velocity but in case of micro rotation increases as R increases. Figure 10 shows the translational velocity profiles with different values of Radiation parameter F The radiation parameter F defines the relative contribution of conduction heat transfer to thermal radiation transfer. The effect of increasing the radiation parameter F is to increase the translational velocity. This is because when the intensity of heat generated through thermal radiation is increased, the bond holding the components of the fluid particles is easily broken and the fluid velocity increased. Figures 11 and 12 represents the microrotationvariations and temperature variations as radiation parameter increases both microrotation and temperature increases.

Figure 13 indicates the variations of translational velocity profiles with different values of diffusion-thermo parameter (or Dufour number) Df. The diffusion-thermo (Dufour) effects refer to heat flux produced by a concentration gradient. The fluid velocity increases with increase in Dufour number. The effect of increasing the value of the Dufour number is to increase the boundary layer. Figure 14, shows the influence of Dufour number in micro rotation profiles. The microrotation profiles increases as the Dufour number increases.

TABLE 1. Effect of F, S, Df and R on C_f when $Q = 0$ and Kr=0.

				Olajuwon [7]	Present values
F	S	Df	R	C_f	C_f
0.5	2.5	0.02	0.5	-10.5322	-10.532202
1.0	2.5	0.02	0.5	-10.0297	-10.029705
0.5	5.0	0.02	0.5	-12.9772	-12.977203
0.5	2.5	1.0	0.5	-4.9692	-4.969201
0.5	2.5	0.02	1.0	-9.5204	-9.520408

TABLE 2. Effect of F, S, Df and R on C_w when $Q = 0$ and Kr=0.

				Olajuwon [7]	Present values
F	S	Df	R	C_w	C_w
0.5	2.5	0.02	0.5	3.6452	3.645192
1.0	2.5	0.02	0.5	3.7879	3.787905
0.5	5.0	0.02	0.5	6.5960	6.596012
0.5	2.5	1.0	0.5	3.7042	3.704211
0.5	2.5	0.02	1.0	7.2903	7.290307

TABLE 3. Effect of F, S, and Df on Nu when $Q = 0$ and Kr=0.

			Olajuwon [7]	Present values
F	S	Df	Nu	Nu
0.5	2.5	0.02	1.0215	1.021512
1.2	2.5	0.02	0.6548	0.654803
0.5	5.0	0.02	2.0430	2.043010
0.5	2.5	1.0	0.3403	0.340305

TABLE 4. Effect of S on Sh when $Q = 0$ and Kr=0.

	Olajuwon [7]	Present values
S	Sh	Sh
4.0	0.6400	0.800000
5.0	0.6400	0.800000

The influence of diffusion-thermo parameter Df on temperature profiles is depicted in Figure 15, it is noticed that the diffusion-thermo effect on the temperature is highly significant, as the temperature profiles in the presence of diffusion are higher in comparison to absence of Dufour effect. Fluid temperature increases with the increase in the Dufour number. Thermal boundary layer thickness increase considerably in the presence of Dufour effect. Figure 16, shows the diffusion thermo effect on concentration profiles. It is seen that the concentration profiles decreases with the increases of Dufour number. The Dufour effect is the energy flux duo to a mass gradient as a coupled effect of irreversible processes.

Figures 17 to 19 represent the influence of chemical reaction parameter Kr on the translation velocity, micro rotation and concentration profiles respectively. Increasing the chemical reaction parameter Kr produces a decrease in the concentration. In turn, this causes the concentration buoyancy effects to decrease as Kr increases. Consequently, less flow is induced along the plate resulting in decrease in the fluid translation velocity in the boundary layer. In count increasing the chemical reaction parameter Kr leads to decrease in the translational velocity, concentration in the boundary layer whereas microrotation distribution increases as Kr increases.

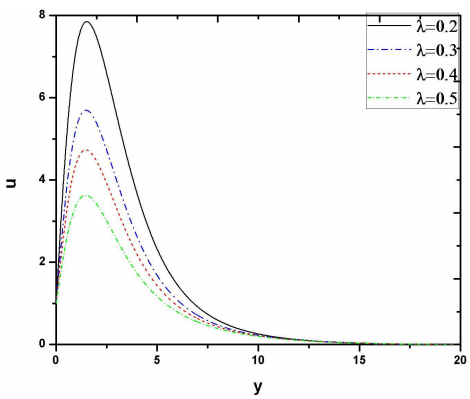

FIGURE 2. Velocity profiles for λ.

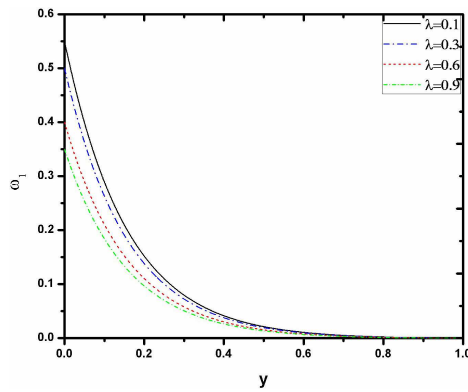

FIGURE 3. Microrotation profiles for λ.

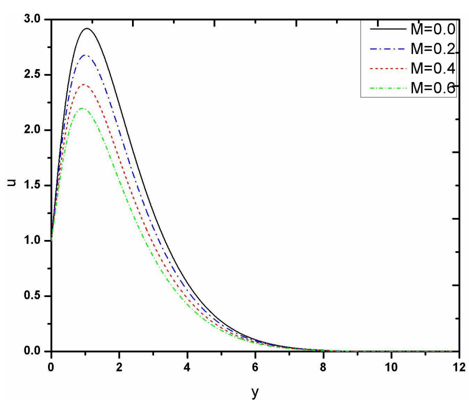

FIGURE 4. Velocity profiles for M.

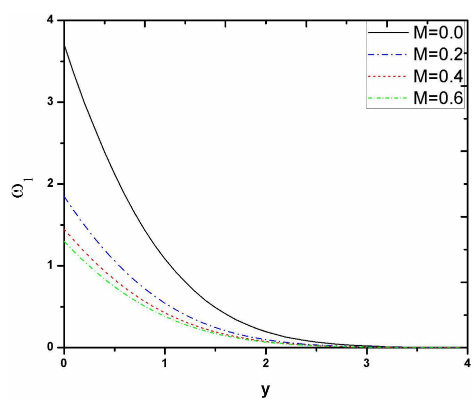

FIGURE 5. Microrotation profiles for M.

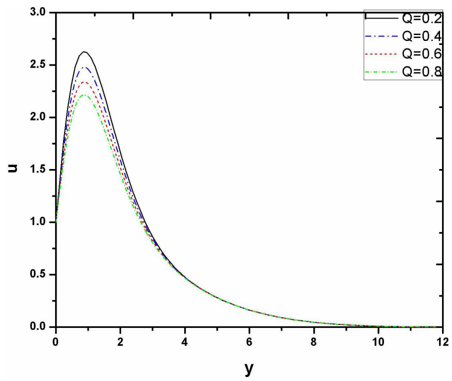

FIGURE 6. Velocity profiles for Q.

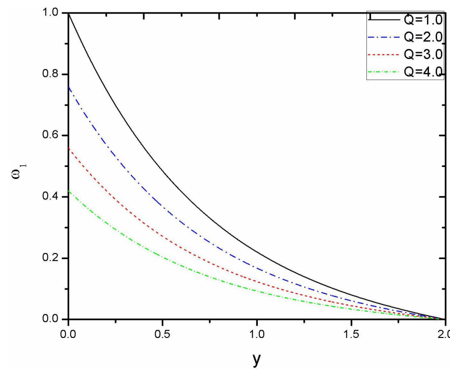

FIGURE 7. Microrotation profiles for Q.

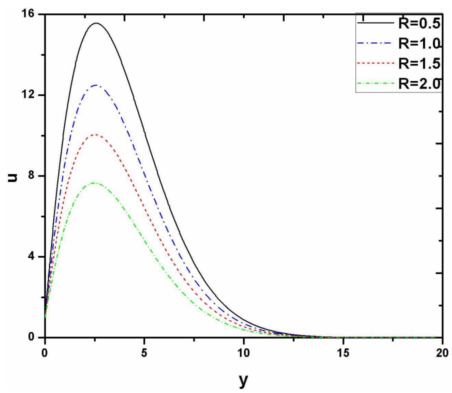

FIGURE 8. Velocity profiles for R.

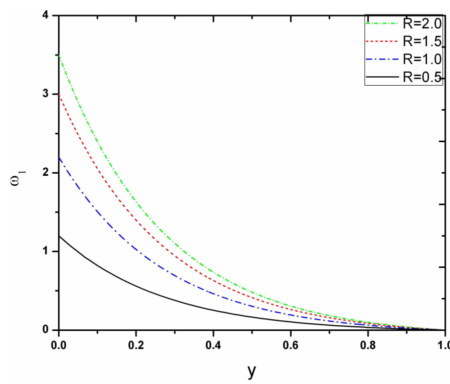

FIGURE 9. Microrotation profiles for R.

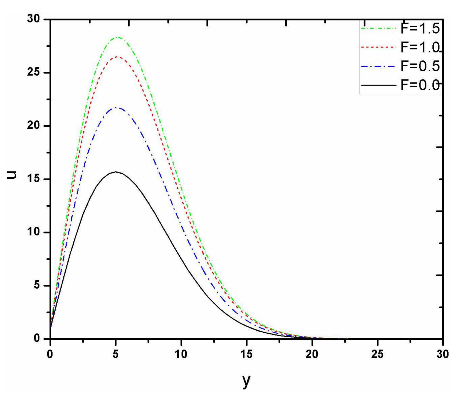

FIGURE 10. Velocity profiles for F.

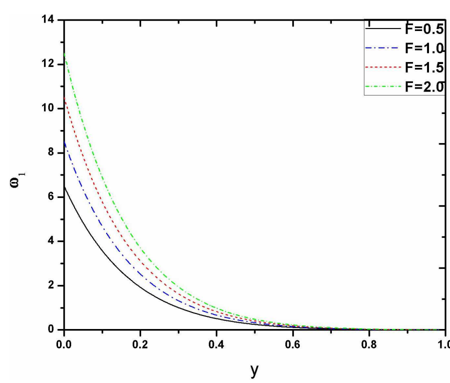

FIGURE 11. Microrotation profiles for F.

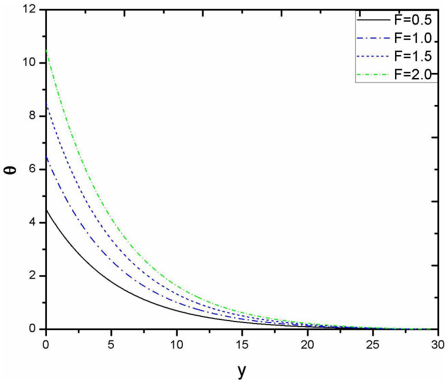

FIGURE 12. Temperature profiles for F.

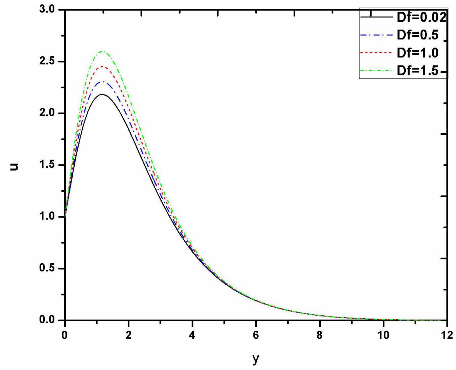

FIGURE 13. Velocity profiles for Df.

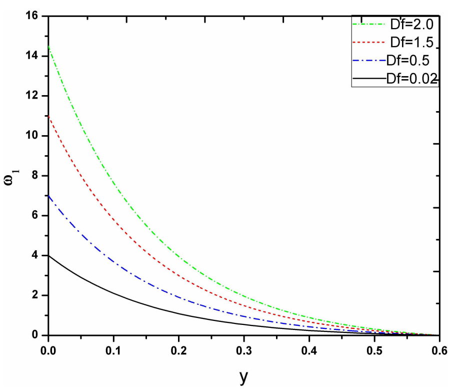

FIGURE 14. Microrotation profiles for Df.

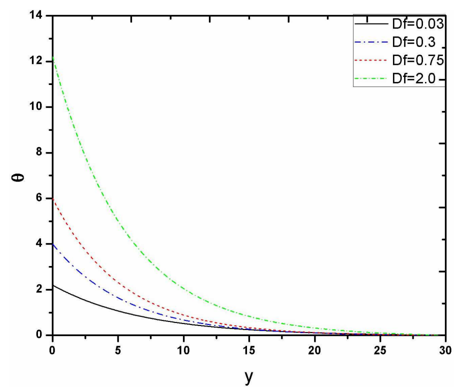

FIGURE 15. Temperature profiles for Df.

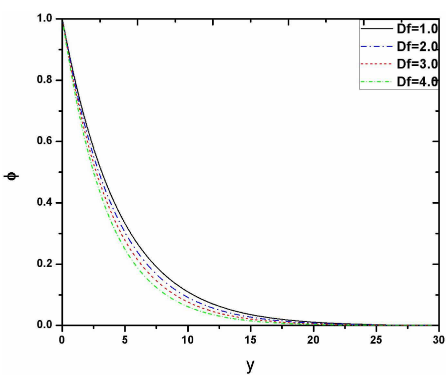

FIGURE 16. Concentration profiles for Df.

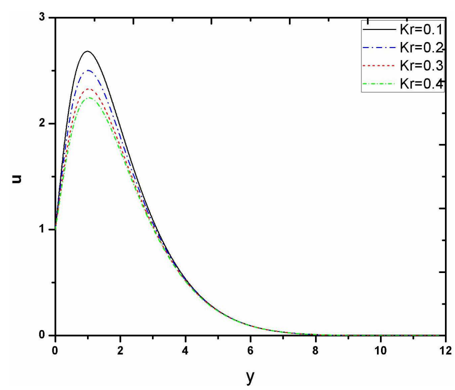

FIGURE 17. Velocity profiles for Kr.

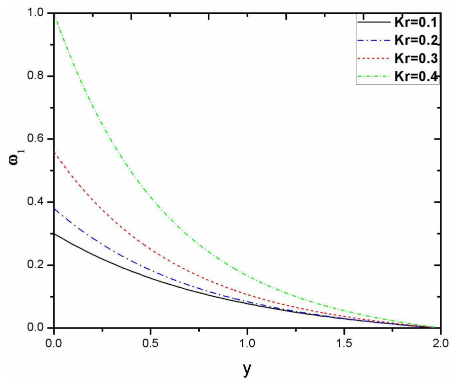

FIGURE 18. Microrotation profiles for Kr.

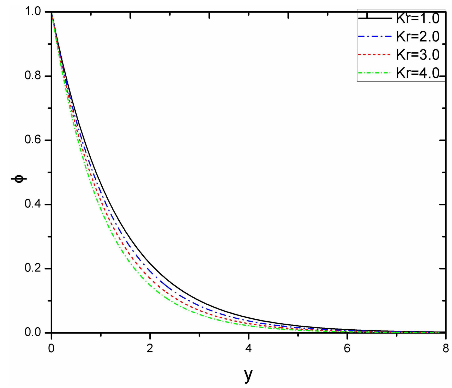

FIGURE 19. Concentration profiles for Kr.

7. Conclusions

The purpose of this study is to extend the work of Olajuwon [7], consider the problem of diffusion-thermo, heat absorption and homogeneous chemical reaction effects on an unsteady magnetohydrodynamic free convection flow in a micropolar fluid. The governing equations are solved numerically by using the finite element method. The effects of the various parameters on translation velocity, micro-rotation, temperature and concentration profiles are discussed. From the Present numerical study the final remarks can be listed as follows:

(1) The momentum boundary layer field decreases as the increasing values of λ, M, Q, R, and Kr. But in case of F and Df momentum boundary layer increases.
(2) The Micropolar field decreases as the increasing of Viscosity ratio, Magnetic parameter and heat absorption increases but in case of rotational parameter, thermal radiation, dufour and chemical reaction it shows reverse effect.
(3) As Thermal radiation, dufour number parameters increases, the thickness thermal boundary layer increases.
(4) As increase in physical parameter Df and Kr cause to increase thickness of concentration boundary layer.

In Tables 1 to 4, we presented the values of skin friction C_f, Couple stress coefficient C_w, Nusselt number Nu and Sherwood number Sh in tabular form. These results are in good agreement with the results obtained by Olajuwon [7].

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References

1. A. C. Eringen, *Theory of thermo fluids*, J. Math. Anal. Appl. **38** (1972), 480–496.
2. Y. J. Kim, J. C. Lee, *Analytical studies on MHD oscillatory flow of a micropolar fluid over a vertical porous plate*, Surf. Coat. Technol. **171** (2003), 187–193.
3. G. Lukaszewicz, *Micropolar fluids-Theory and Application* Birkhauser, Boston, 1999.
4. A. J. Chamkha *MHD flow of a uniformly stretched vertical permeable surface in the presence of heat generation/absorption and a chemical reaction*, Int. Commun. Heat Mass Transfer **30** (2003), 413–422.
5. E. R. G. Eckert, R. M. Drake, *Analysis of Heat and Mass transfer*, McGraw-Hill, New York, 1972.
6. B. I. Olajuwon, *Convection Heat and mass transfer in a hydromagnetic flow of a second grade fluid in the presence of thermal radiation and thermal diffusion*, Int. Commun. Heat Mass Transfer **38** (2011), 1557–1563.
7. B. I. Olajuwon, J. I. Oahimire, *Unsteady free convection heat and mass transfer in an MHD micropolar fluid in the presence of thermo diffusion and thermal radiation*, Int. J. Pure Appl. Math. **84** (2013), 15–37.
8. J. A. Rao, S. Sivaiah, *Chemical reaction effects on unsteady MHD floe past semi-infinite vertical porous plate with viscous dissipation*, Appl. Math. Mech., Engl. Ed. **32** (2011), 1065–1078.
9. S. Sivaiah, R. Srinivasa-Raju, *Finite element solution of heat and mass transfer flow with hall current, heat source and viscous dissipation*, Appl. Math. Mech., Engl. Ed. **34** (2013), 559–570.
10. R. Muthucumaraswamy, *Effects of a chemical reaction on a moving isothermal surface with suction*, Acta Mech. **155** (2002), 65–72.
11. R. Muthucumaraswamy, S. Meenakshisundaram, *Theoretical study if chemical reaction effects on vertical oscillating plate with variable temperature*, Theor. Appl. Mech. (Belgrade) **33**(3)(2006), 245–257.
12. K. Das, *Effect of chemical reaction and thermal radiation on heat and mass transfer flowof MHD micro polar fluid in a rotating frame of reference*, Int. J. Heat Mass Transfer **54** (2011), 3505–3513.
13. S. Shivaiah, J. Anand Rao, *Chemical reaction effects on an unsteady MHD free convective flow past an infinite vertical porous plate with constant suction and heat source*, Int. J. Appl. Math. Mech. **7** (2011), 98–118.
14. A. J. Chamkha, R. A. Mohamed, S. E. Ahmed, *Unsteady MHD natural convection from a heated vertical porous plate in a micropolar fluid with joule heating, chemical reaction and radiation effects*, Meccanica **46** (2011), 399–411.
15. S. Sivaiah, J. Anand Rao, *Chemical reaction effects on an unsteady MHD free convective flow past a vertical porous plate in the presence of suction or injection*, Theor. Appl. Mech. (Belgrade) **39** (2012), 185–208.
16. A. A. Bakr, *MHD free convection and mass transfer flow of a micro polar fluid with oscillatory plate velocity and constant heat source in a rotating frame of reference*, Commun. Nonlinear Sci. Numer. Simul. **16** (2001), 698–710.
17. K. Das, *Effect of mass transfer on MHD free convection flow near a moving vertical plate of a radiating and chemically reacting fluid*, J. SibFU Math. Phys. **4**(2011), 18–34.
18. R. A. Damesh, M. Q. Odat, A. J. Chamka, A. Benbella Shannk, *Combined effect of heat generation/absorption and first order chemical reaction on micropolar fluid flows over uniform stretched permeable surface*, Int. J. Therm. Sci. **48** (2009), 1658–1663.
19. R. Ganapathy, *A note on oscillatory Coquette flow in a rotating system*, J. Appl. Mech. **61**(1) (1994), 208–209.
20. K. J. Bathe, *Finite Element procedures*, Printice–Hall, New Jersey, 1996.
21. J. N. Reddy, *An introduction to the Finite element method*, McGraw-Hill, New York, 1985.
22. T. J. Chung, *Finite element analysis in fluid dynamics*, McGraw-Hill, New York, 1978.
23. J. J. Connor, C. A. Brebbia, *Finite element Techniques for fluid flow*, Butterworths, London, 1976.

ЕФЕКТИ ДИФУЗИОНО-ТЕРМАЛНИХ И ХЕМИЈСКИХ РЕАКЦИЈА НА НЕСТАБИЛАН MHD СЛОБОДАН КОНВЕКТИВНИ ТОК У МИКРОПОЛАРНОМ ФЛУИДУ

Резиме. Разматра се нумеричка анализа граничног слоја у односу на ефекте термалне дифузије, апсорпције топлоте и хомогене хемијске реакције на магнетнохидродинамички ток нестишљивог, ламинарног, хемијски реагујућег микрополарног флуида који пролази поред полу-бесконачне вертикалне порозне плоче. Одговарајуће парцијалне диференцијалне једначине се решавају нумерички коришћењем методе коначних елемената. Нумерички резултати су упоређени и утврђено је да су у доброј сагласности са претходним резултатима, као посебном случају овог истраживања. Ефекти различитих важних параметара проблема на брзине, микроротације, температуре и концентрације поља у граничном слоју, су дискутовани и објашњени графички. Такође, ефекти одговарајућих параметара на локалном површинском коефицијенту трења, спрегнутог напона зида и стопе преноса топлоте и масе у зависности од локалних Нуселтовох и Шервудових бројева су нумерички представљена у облику табела.

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