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MHD EFFECTS ON FREE CONVECTIVE FLOW OF A FLUID THROUGH A POROUS MEDIUM IN CHEMICAL REACTION AND THERMAL RADIATION GENERATION AND CHEMICAL REACTION

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ABSTRACT

We study on MHD Effects on Free Convective Flow of a Fluid through a Porous Medium in chemical reaction and thermal radiation an analysis is presented to study the MHD free convection with thermal radiation and mass transfer of fluid through a porous medium occupy a semi –infinite region of the space bounded by an infite vertical porous plate with constant suction velocity in the presence of chemical reaction, internal heat source ,viscous and darcy's. The highly nonlinear coupled differential equations governing the boundary layer flow, heat, and mass transfer are solved by using a two-term perturbation method with Eckert number E as a perturbation parameter. The results are obtained for velocity, angular velocity, temperature, concentration, Nusselt number, and Sherwood number. The effect of various material parameters on flow, heat, and mass transfer variables is discussed and illustrated graphically.

1. INTRODUCTION

Magneto-hydrodynamics is the branch of physics which studies the interaction between the flow of electrically conducting fluids and electromagnetic fields. It is an inter disciplinary science which is a combination of two familiar sciences: fluid dynamics which is a study of the flow of gases and liquids, and electromagnetism which provides relationships between electric and magnetic fields and current. In MHD fluid must be electrical conducting and non-magnetic, this covers the wide range of materials from electrolytes and liquid metals to partially or fully ionized gases Coupled heat and mass transfer problems in presence of chemical reaction are of importance in many processes and have, therefore, received considerable amount of attention in recent years. In processes such as drying, distribution of temperature and moisture over agricultural fields and graves of fruit trees, damage of crops due to freezing, evaporation at the surface of a water body, energy transfer in a wet cooling tower, and flow in a desert cooler, heat and mass transfer occur simultaneously. Possible applications of this type of flow can be

1) found in many industries. For example, in the electric power industry, among the methods of generating electric power is one in which electrical energy is extracted directly from a moving conducting fluid. Chemical reactions can be modeled as either homogeneous or heterogeneous processes. This depends on whether they occur at an interface or as a single phase volume reaction. A homogeneous reaction is one that occurs uniformly throughout a given phase. The species generation in a homogeneous reaction is the same as internal source of heat generation. On the other hand, a heterogeneous reaction takes place in a restricted area or within the boundary of a phase. It can therefore be treated as a boundary condition similar to the constant heat flux condition in heat transfer. The study of heat and mass transfer with chemical reaction is of great practical importance to engineers and scientists because of its almost universal occurrence in many branches of science and engineering. Convection problems associated with heat sources within fluid-saturated porous media are of great practical significance in a number of practical applications in geophysics and energy-related problems, such as recovery of petroleum resources, geophysical flow, cooling of underground electric cables, storage of nuclear waste materials, ground water pollution, fiber and granular insulations, solidification of costing, chemical catalytic reactors, and environmental impact of buried heat generating waste. Effect of heat generation or absorption on free convective flow with heat and mass transfer in geometries with and without porous media has been studied by many scientists and technologists The study of flow and heat transfer for an electrically conducting polar fluid past a porous plate under the influence of a magnetic field has attracted the interest of many investigators in view of its applications in many engineering problems such as magnetohydrodynamic MHD generator, plasma studies, nuclear reactors, oil exploration, geothermal energy extractions, and the boundary layer control in the field of aerodynamics Polar fluids are fluids with microstructure belonging to a class of fluids with nonsymmetrical stress tensor. Physically, the represented fluids are consisting of randomly oriented particles suspended in a viscous medium Ibrahim et al. studied unsteady magnetohydrodynamic micropolar fluid flow and heat transfer over a vertical porous plate through a porous medium in the presence of thermal and mass diffusion with a constant heat source

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2. REVIEW OF LITERATURE

2) Das *et al*. 1 have studied the effects of mass transfer on the flow past impulsively started infinite vertical plate with constant heat flux and chemical reaction. Diffusion of a chemically reactive species from a stretching sheet.
3) Anderson *et al.* [2] have analyzed the effects of chemical reaction, heat and mass transfer on laminar flow along a semi-infinite horizontal plate.
4) Muthucumaraswamy and Ganesan [4]: have studied the impulsive motion of a vertical plate with heat flux/mass flux/suction and diffusion of chemically reaction species.
5) Muthucumaraswamy [6] has analyzed the effects of a chemical reaction on a moving isothermal vertical surface with suction.
6) Ghaly and Seddeek [8]: have discussed the Chebyshev finite difference method for the effects of chemical reaction, heat and mass transfer on laminar flow along a semi-infinite horizontalplate with temperature-dependent viscosity.
7) Kandasamy *et al.* [9]: studied effects of chemical reaction, heat and mass transfer along a wedge with heat source and concentration in the presence of suction or injection, and chemical reaction, heat and mass transfer on MHD flow over a vertical stretching surface with heat source and thermal stratification effects.
8) Mohamed *et al.*: have discussed the finite element method for the effect of a chemical reaction on hydromagnetic flow and heat transfer of a heat generation fluid over a surface embedded in a non-Darcian porous medium.
9) Rahman and Sattar: studied MHD convective flow of a micropolar fluid past a vertical porous plate in the presence of heat generation/absorption.
10) Kim: investigated MHD convection flow of polar fluids past a vertical moving porous plate in a porous medium.
11) Helmy [30] obtained the solution for a magneto-hydromagnetic unsteadyfree convection flow past a vertical porous plate for a Newtonian fluid and a special type of non-Newtonion fluid known as micropolar fluids.
12) Ogulu: studied the influence of Mathematical Problems in Engineering 3radiation absorption on unsteady free convection and mass transfer flow of a polar fluid in the presence of uniform magnetic field.
13) Anjali Devi and Kandasamy: have analyzed the effects of chemical reaction, heat and mass transfer on MHD flow past a semi infinite plate. The flow and mass transfer on a stretching sheet with a magnetic field and chemically reactive species
14) Raptis and Perdikis: have analyzed the effect of a chemical reaction of an electrically conducting viscous fluid on the flow over anonlinearly quadratic semi-infinite stretching sheet in the presence of a constant magnetic field which is normal to the sheet.
15) Seddeek: has studied the finite element for the effects of chemical reaction, variable viscosity, thermophoresis, and heat generation/absorption on a boundary layer hydromagnetic flow with heat and mass transfer over a heat source.
16) Sharma and Thakur: have analyzed the effects of MHD on couple stress fluid heated from below in porous medium.
17) V. Sharma and S. Sharma: have discussed effects of thermosolutal convection of micropolar fluids with MHD through a porous medium. The effect of heat and mass transfer on MHD micropolar flow over a vertical moving porous plate in a porous medium has studied by
18) Kim [38] The effect of rotation on a layer of micropolar ferromagnetic fluid heated from below saturating a porous medium
19) Sunil *et al.* [39] many processes are new engineering areas occuring at high temperatures, and m knowledge of radiate heat transfer becomes very important for the design of the pertinent equipment. Nuclear power planets gas turbines and the various propulsion devices for aircraft, missiles, satellites, and space vehicles of radiation effects on the various types of flows are quite complicated. On the other hand, heat transfer by simultaneous free convection and thermal radiation in the case of a polar fluid has not received as much attention. This is unfortunate because thermal radiation plays an important role in determining the overall surface heat transfer in situations where convective heat transfer coefficients are small, as is the case in free convection such situations are common in space technology The effects of radiation on the flow and heat transfer of micropolar fluid past a continuously moving plate have been studied by many authors.
20) Abo-Eldahab and Ghonaim Ogulu has studied the oscillating platetemperature flow of a polar fluid past a vertical porous plate in the presence of couple stresses and radiation.
21) Rahman and Sultana investigated the thermal radiation interaction of the boundary layer flow of micropolar fluid past a heated vertical porous plate embedded in a porous medium with variable suction as well as heat flux at the plate.
22) Recently, Mohamed and Abo-Dahab investigated the effects of chemical reaction and thermal radiation on the heat and mass transfer in MHD micropolar flow over a vertical moving porous plate in a porous medium with heat generation.

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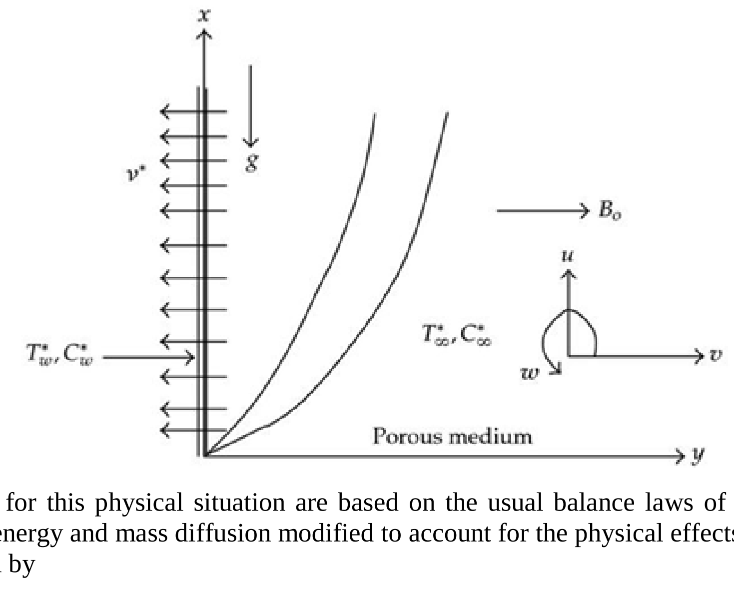
The object of the present paper is to study the two-dimensional steady radiative heat and mass transfer flow of an incompressible, laminar, and electrically conductive viscous dissipative polar fluid flow through a porous medium, occupying a semi-infinite region of the space bounded by an infinite vertical porous plate in the presence of a uniformtransverse magnetic field, chemical reaction of the first-order and internal heat generation. Approximate solutions to the coupled nonlinear equations governing the flow are derived and expression for the velocity, angular velocity, temperature, concentration, the rates of heat and mass transfer, and the skin-friction are derived. Numerical calculations are carried out; the purpose of the discussion of the results which are shown on graphs and the effects of the various dimensionless parameters entering into the problem on the velocity, angular velocity, temperature, concentration, the skin-friction, wall heat transfer, and mass transfer rates are studied. 4 Mathematical Problems in Engineering

3. FORMULATION OF THE PROBLEM

The basic equations of mass, linear momentum, angular momentum, energy and concentration for steady flow of polar fluids with the vector fields are as follows:
We consider a two dimensional Carisian coordinates ($x*,\ y*$) steady hydromagnetic free convection with thermal radiation and mass transfer flow of laminar, viscous, incompressible, and heat generation polar fluid through a porous medium occupying a semiinfinite region of the space bounded by an infinite vertical porous plate in the presence of a transverse magnetic field and chemical reaction. $x*$ is taken along the vertical plate and $y*$ is normal to it. The velocity, the angular velocity, the temperature, and the species concentration fields are (u^*, V^*0) $(0,\ 0, W^*)\ T^*$ and c^* respectively. The surface is maintained at a constant temperature $T*\ w$ different from the porous medium temperature $T*\infty$ sufficiently a way from the surface and allows a constant suction. The fluid is assumed to be a gray, emitting absorbing, but non-scattering medium and the Rosseland approximation is used to describe the radiative heat flux in the energy equation. The radiative heat flux in the $x*$-direction is considered negligible in comparison to the $y*$-direction. A magnetic field of uniform strength is applied transversely to the direction of the flow. The magnetic Reynolds number of the flow is taken to be small enough so that the induced magnetic field can be neglected. No electric field is assumed to exit and both viscous and magnetic dissipations are neglected. A heat source is placed within the flow to allow possible heat generation effects. The concentration of diffusing species is assumed to be very small in comparison with other chemical species which are present; the concentration of species far from the surface $C*\infty$ is infinitesimally small 49 and hence the Soret and Duffer effects are neglected. However, the effects of the viscous dissipation and Darcy dissipation ignoring the contribution due couple stresses as a first approximation are accounted in the energy balance equation. The chemical reaction is taking place in the flow and all thermophysical properties are assumed to be constant. The flow is due to buoyancy effects arising from density variations caused by differences in the temperature as well as species concentration. The diagrammatic of the problem is displayed in Figure 1.



The governing equations for this physical situation are based on the usual balance laws of mass, linear momentum, angular momentum, and energy and mass diffusion modified to account for the physical effects mentioned above.
These equations are given by

The continuity equation

$$:\frac{\partial u}{\partial x}+\frac{\partial v}{\partial x}=0 \tag{1}$$

The momentum equation:

$$\frac{\partial y}{\partial t}+u\frac{\partial y}{\partial x}+v\frac{\partial y}{\partial y}=v\frac{\partial^2 y}{\partial y^2}+g\beta(T-T_\infty)-\frac{\sigma B_0^2 u}{\rho} \tag{2}$$

The energy equation:

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{k}{\rho c_p}\frac{\partial^2 T}{\partial y^2} - \frac{1}{\rho c_p}\frac{\partial q_r}{\partial y}\frac{v}{c_p}\left(\frac{\partial u}{\partial y}\right)^2 + \tau\{D_B\left(\frac{\partial T}{\partial y}\frac{\partial C}{\partial y}\right) + \frac{D_T}{T_\infty}((\frac{\partial T}{\partial y})^2 \quad (3)$$

The concentration equation:

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D_B\frac{\partial^2 C}{\partial y^2} + \frac{D_T}{T_\infty}\frac{\partial^2 T}{\partial y^2} \quad (4)$$

The initial and boundary value problems are

T = 0, u = Dx, T = T_∞, C = C_∞ every where

t ≥ $0, u = 0, v = 0$, T = T_∞, C = C_∞ $at\ x = 0$

v = 0, u = Dx, T = T_w, C = C_w at y = 0

u = 0 = v, T→ T_∞, C→ C_∞ at y→ ∞ (5)

The Rosseland approximation is express for radiative heat flux and leads to the form

$$q_r = \frac{4\sigma}{3k}\frac{\partial T^4}{\partial y} \quad (6)$$

where σ is the Stefan –Boltzmann constant and k is the absorption coefficient. T^4 may be expressed as a linear function of the temperature, then Taylor's series for $T^4$is about T_∞, after neglecting higher order terms.

$$T^4 = 4T_\infty^3 - 3T_\infty^4$$

Introducing the following non dimensional variables,

$$X = \frac{xU_o}{v},\ Y = \frac{yU_o}{v},\ U = \frac{u}{U_o},\ V = \frac{v}{U_o},\ = \frac{tU_0^2}{v},\ \overline{T} = \frac{T - T_\infty}{T_w - T_\infty},\ \overline{C} = \frac{C - C_\infty}{C_w - C_\infty} \quad (8)$$

Then (1) to (5) be comes

$$\frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} = 0 \quad (9)$$

$$\frac{\partial U}{\partial \tau} + u\frac{\partial U}{\partial X} + v\frac{\partial U}{\partial Y} = v\frac{\partial^2 U}{\partial Y^2} + G_r\overline{T} - MU \quad (10)$$

$$\frac{\partial \overline{T}}{\partial t} + u\frac{\partial \overline{T}}{\partial X} + v\frac{\partial \overline{T}}{\partial Y} = \frac{k}{\rho c_p}\frac{\partial^2 T}{\partial y^2} = [(\frac{1+R}{P_r})\frac{\partial^2 \overline{T}}{\partial Y^2})] + E_C((\frac{\partial U}{\partial Y})^2 + N_b\frac{\partial \overline{T}}{\partial Y}\frac{\partial \overline{C}}{\partial Y} + N_b(\frac{\partial \overline{T}}{\partial Y})^2 \quad (11)$$

$$\frac{\partial \overline{C}}{\partial t} + u\frac{\partial \overline{C}}{\partial X} + v\frac{\partial \overline{C}}{\partial Y} = \frac{1}{L_e}\frac{\partial^2 \overline{C}}{\partial Y^2} + \frac{\partial^2 \overline{T}}{\partial Y^2} \quad (12)$$

The non – dimensional boundary value conditions are

T ≤0, U =0 =V, $\overline{T}$=0 = $\overline{C}$ every where

t > $0, U = 0, V = 0, \overline{T} = 0 = \overline{C}\ \ at\ X = 0$ (13)

U=1, V=0. $\overline{T} = 1 = \overline{C}$ at Y=0

U =0 =V, $\overline{T} = 0 = \overline{C}$ $as\ Y\ tends\ to$ infinite

Where the magnetic para meters M=$\frac{\sigma B_0^2 v}{\rho}$, Grashof number G_r= g $\frac{g\beta(T - T_\infty)w}{U_0^2}$, radiation [parameter R= $\frac{16\sigma T_\infty^3}{3kx}$ Pranditl number p_r=$\frac{e}{a}$, Eckert number E_C=$\frac{U_0^2}{C_p(T_w - T_\infty)}$. Lewis number L_e=$\frac{v}{D_b}$, Brownaian parameter $N_b = \frac{\tau D_B(C_w - C_\infty)}{v}$ and thermophoresis parameter N_1=$\frac{\tau D_B(T_w - T_\infty)}{T_\infty v}$

4. METHODS: NUMERICAL COMPUTATION

In order to solve the non-similar unsteady coupled nonlinear partial differential equations (Equations 8, 9, 10, and 11), the explicit finite difference method has been developed. For this, a rectangular region of the flow field is chosen, and the region is divided into a grid of lines parallel to X and Y axes, where the X-axis is taken along the plate and the Y-axis is normal to the plate. Here, the plate of height X max(=100) is considered, i.e., X varies from 0 to 100 and assumed Y max(=25) as corresponding to Y→ ∞, i.e., Y varies from 0 to 25. There are m (=125) and n (=125) grid spacing in the X and Y directions, It is assumed that ΔX and ΔY are constant mesh sizes along the X and Y directions, respectively, and taken as follows: ΔX = 0.8

5. RESULTS AND DISCUSSION

In order to investigate the problem under consideration, the results of numerical values of non-dimensional velocity, temperature, and species concentration within the boundary layer have been computed for different values of magnetic parameter M, radiation parameter R, Prandtl number Pr, Eckert number Ec, Lewis number Le, Brownian motion parameter Nb, thermo-phoresis parameter Nt, and Grashof number Gr, respectively. To obtain the steady state solutions of the computation, the calculations have been carried out up to non-dimensional = 5, 20 and 50 and displays the entire step with a different pattern. Here, it is observed that when the values of R increase, then the temperature profiles increases; when the values of Ec increase, then the temperature profiles also increase; when the values of Pr increase, then the temperature profiles decrease; and when the values of N_b increase, then the temperature profiles increase.

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In Figures 4 and 5, the concentration distribution is plotted respectively for different values of N_t and L_e. The non-dimensional time considered here is τ = 5, 20 and 50 and displays the entire step with a different pattern. Here, it is observed that when the values of N_t increase, then the concentration profiles increase, but when the values of Le increase, then the concentration profiles decrease. From the present results and the result obtained by Khan and Pop [19], it was observed that the flow field shows the same trend with the variation of magnetic parameter M, radiation parameter R, Prandtl number Pr, Eckert number E_c, Lewis number L_e, Brownian motion parameter N_b, thermophoresis parameter N_t, and Grashof number G_r. However, the important part of this work is its comparison with the previous work, i.e., the present study is the unsteady case when the values of magnetic parameter M, radiation parameter R, Eckert number E_c, and Grashof number G_r are considered zero.

CONCLUSIONS

An unsteady free convection boundary-layer flow of a nanofluid due to a stretching sheet is studied with the influence of magnetic field and thermal radiation. The explicit finite difference technique with stability and convergence analysis has been employed as a solution technique to complete the formulation of the unsteady model. For the unsteady case (time-dependent), the non-dimensional time considered here is τ = 5, 20 and 50 and displays with the entire step and a different line pattern. The results are presented for the effect of various parameters. The velocity, temperature, and concentration effects on the sheet are studied and shown graphically. time τ = 5 to 80. The velocity, temperature, and concentration profiles don't show any change after non-dimensional time τ = 50. Therefore, the solution for $\tau \geq$ 50 is the steady-state solution. The graphical representation of the problem has been shown in Figures 3, 4, 5, 6, 7, 8, 9, and 10. and the values of magnetic parameter M, radiation parameter R, Eckert number Ec, and Grashof number Gr are considered zero .From the comparison, excellent agreement is observed. In Figures 3, 4, 5, 6, 7, 8, 9, and 10, the dimensionless velocity, temperature, and concentration distributions are plotted against Y for the different non-dimensional time τ = 5 to 50 and corresponding values of Grashof number Gr, magnetic parameter M, radiation parameter R, Eckert number Ec, Prandtl number Pr, Brownian motion parameter Nb, thermophoresis parameter Nt, and Lewis number Le, respectively. In Figures 3 and 4, the velocity distribution is plotted respectively for different values of Gr and M. The non-dimensional time considered here is τ = 5, 20 and 50 and displays the entire step with a different pattern. Here, it is observed that when the values of Gr increase, then the velocity profiles increase and when the values of M increase, then the velocity profiles decrease. In Figures 5, 6, 7, and 8, the temperature distribution is plotted respectively for different values of R, Ec, Pr, and N_b. The non-dimensional time considered here is From the present study, the concluding remarks have been taken as follows:

1. Larger values of the Grashof number showed a significant effect on momentum boundary layer.
2. The effect of the Brownian motion and thermo-phoresis stabilizes the boundary layer growth.
3. The boundary layers are highly influenced by the Prandtl number.
4. Using magnetic field, the flow characteristics could be controlled.
5. The thermal boundary layer thickness increases as a result of increasing radiation.
6. The presence of heavier species (large Lewis number) decreases the concentration in the boundary layer.
7. The Eckert number has a significant effect on the boundary layer growth.
8. the effect of the Prandtl number Pr increase in temperature profile;
9. the effect of the Brownian motion parameter N_b and thermophoretic parameter Nt increase for velocity and temperature profiles whereas a reverse effect can be seen for concentration profile; decreases the concentrationλ
10. the effect of the Lewis number Le and the buoyancy parameter boundary layer; are found to decrease the velocity and concentrationΔ(v) the effects of the chemical reaction parameter profiles; 11. the effects of the Brownian motion parameter Nb and thermophoresis parameter N_t are found to be significant for the skin-friction coefficient and local Nusselt number.

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NOTE:

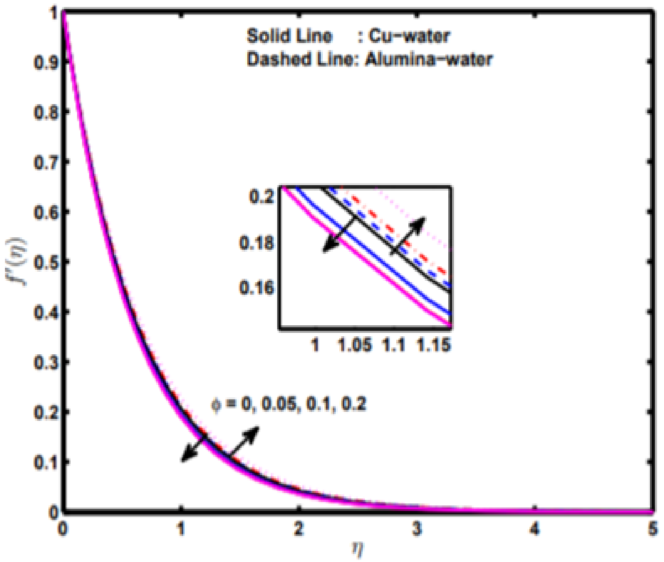

Figure-1: radiation parameters ® effects on temperature profiles M = 0.5, Lr = 1.0, Pr = 6.2, Er = 0.01, Nr = 1.0.

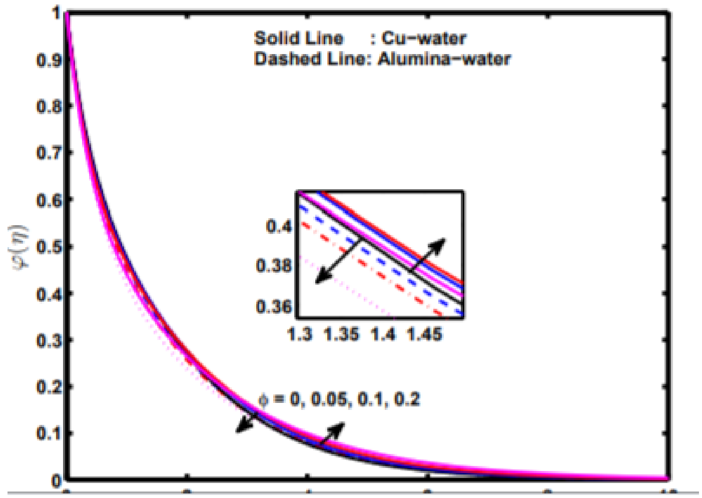

Figure-2: Eckert number (er effects on temperature profiles M = 0.5, Lr = 1.0. Pr = 6.2, Er = 0.01, R = 1.0. Nr = 0.01.

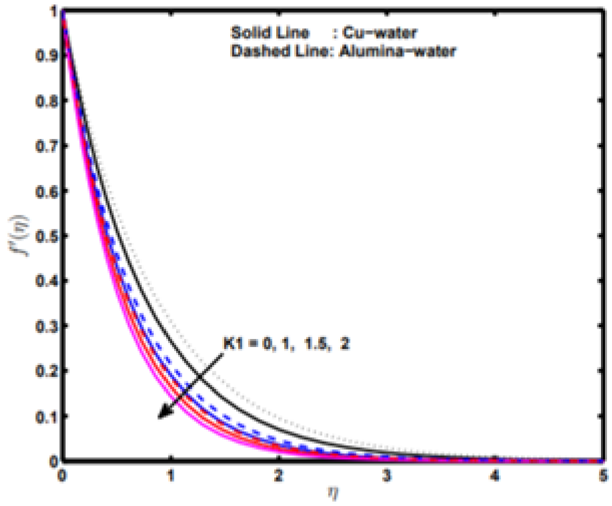

Figure-3: radiation parameters ® effects on temperature profiles M = 0.5, Lr = 1.0. Pr = 6.2, Er = 0.01 Nr =1.0. prandit number (Pr) effects Gr = 0.2. Sc =1.

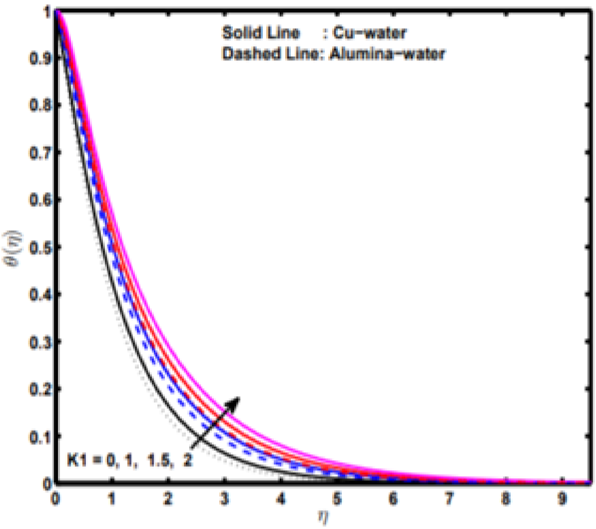

Figure-4: effect of the porous medium parameter effects on temperature profiles M = 0.5, Lr = 1.0. Pr = 6.2 Er = 0.01, Nr = 1.0. prandit number (Pr) effects Gr = 0.2. Sc = 1.

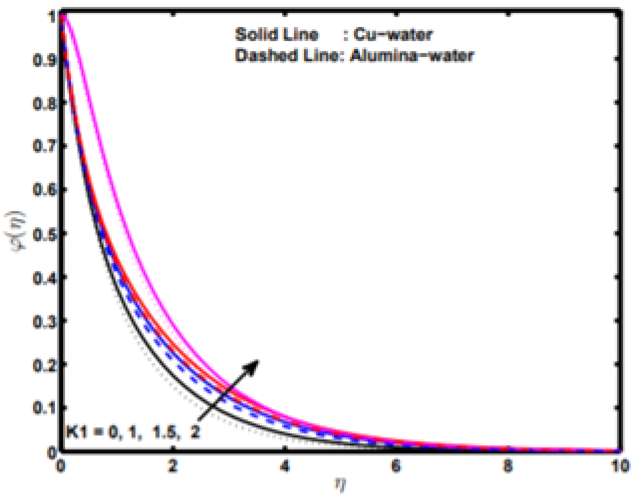

Figure-5: effects on porous medium temperature profiles M = 0.5, Lr = 1.0. Pr = 6.2, Er = 0.01, Nr =1.0. prandit number (Pr) effects Gr = 0.2. Sc =1 $\emptyset = 0.2$.

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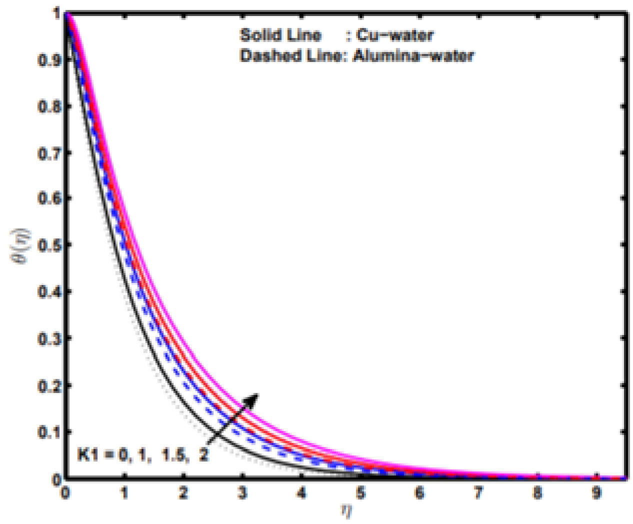

Figure-6: effect of maganetic parameter M on the velocity profile for M = 0.5, Lr = 1.0. Pr = 6.2, Er = 0.01, Nr = 1.0. prandit number (Pr) effects Gr = 0.2, Sc =1, $\emptyset = 0.2$,

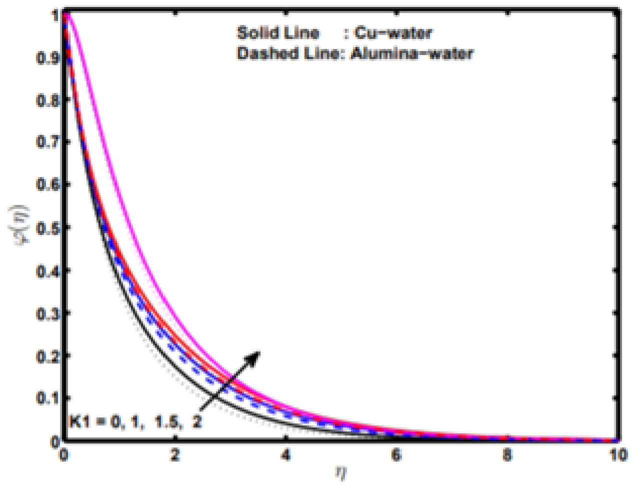

Figure-6: Effect of viscous dissipation parameter Ec on the temperature profile for M = 0.5, Lr = 1.0, Pr = 6.2, Er = 0.01, Nr = 1.0. prandit number (Pr) effects Gr = 0.2. Sc =1, $\emptyset = 0.2$.

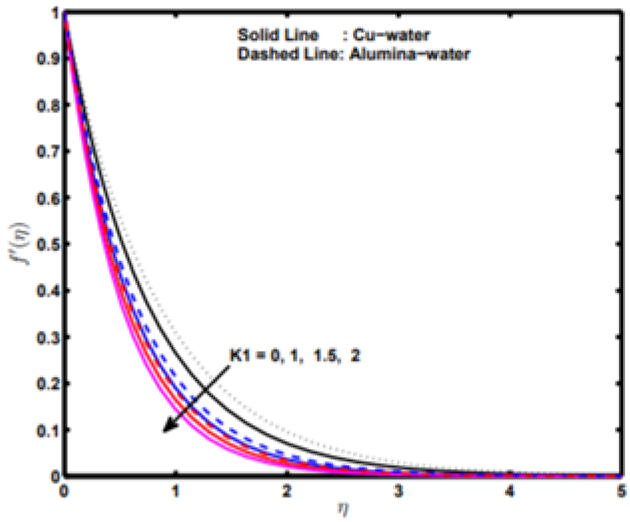

Figure-7: Effect of thermal radiation parameter R on the temperature profile for M = 0.5, Lr = 1.0. Pr = 6.2, Er = 0.01, Nr = 1.0. prandit number (Pr) effects Gr = 0.2. Sc =1 $\emptyset = 0.2$.

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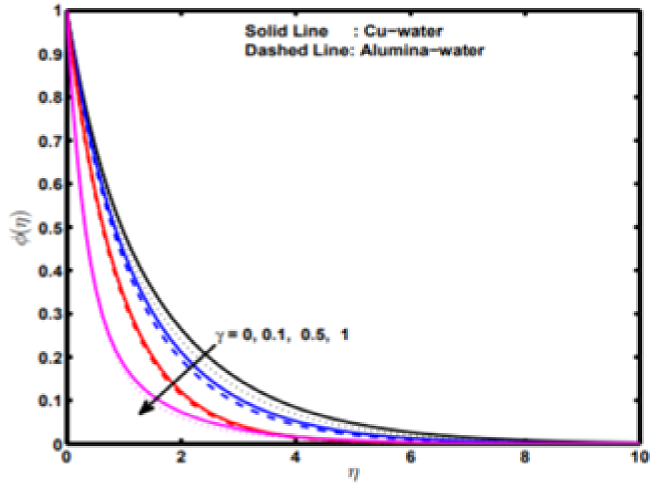

Figure-8: effect of the Schmidt number Sc on concentration profile for M = 0.5, Lr = 1.0. Pr = 6.2, Er = 0.01, Nr = 1.0. prandit number (Pr) effects Gr = 0.2. Sc =1, $\emptyset = 0.2$.

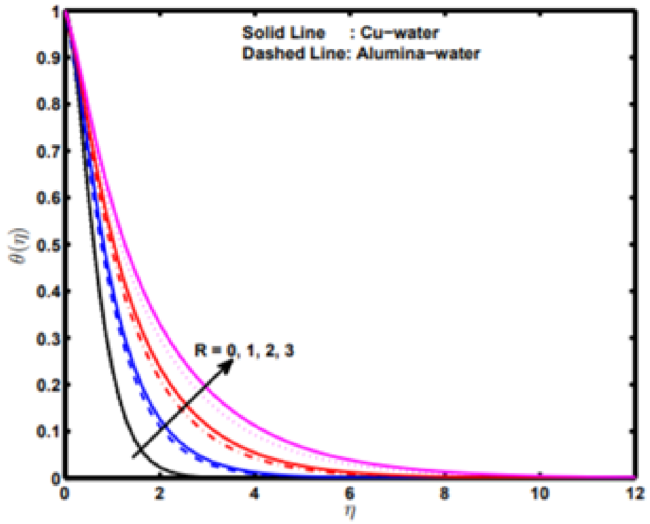

Figure-9: effect of the chemical reaction parameter γ and soret number Sr on concentration profile M = 0.5 Lr = 1.0, Pr = 6.2, Er = 0.01, Nr = 1.0. prandit number (Pr) effects Gr = 0.2. Sc =1 $\emptyset = 0.2$.

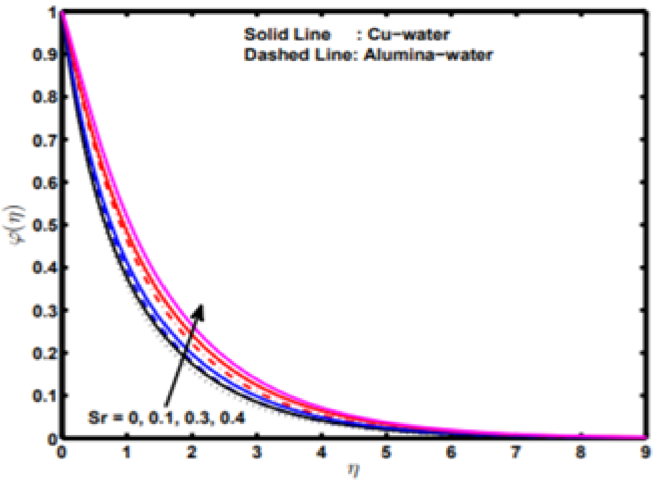

Figure-10: Effect of the chemical reaction parameter γ and soret number Sr on concentration profile for $\emptyset = 0.1$, M = 0.5, Lr = 1.0. Pr = 6.2, Er = 0.01, Nr = 1.0. prandit number (Pr)effects Gr =0.2. Sc =1 $\emptyset = 0.2$.

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