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UNSTEADY MHD CONVECTIVE NANO FLUID FLOW THROUGH POROUS MEDIUMPAST A PLATE WITH SORET EFFECT, CHEMICALAND THERMAL RADIATIONS IN THE PRESENCE OF HALL CURRENT AND ROTATIONS

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Abstract

In this paper, the combined effects of hall current and rotation on unsteady MHD (magneto-hydrodynamics) convective nano fluid flow through porous medium past a plate with soret effect, Chemical reaction and thermal radiation are theoretically investigated. We have investigated the way in which the velocity temperature and concentration profiles as well as the surface skin friction, surface heat flux and surface mass flux depend on the nano particles volume fraction parameter. The analytical solutions of the boundary layer equations are assumed to be oscillatory type and they are obtained by using the small perturbation approximations. The influence of various relevant physical characteristics are presented and discussed. The results are displayed graphically to show the interesting aspects of the nanofluids. It is found that the heat and mass transfer enhancement is caused by the suspending nanoparticles and it becomes more pronounced with the increase of the particle volume fraction.

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Key Words : *Hall current, Rotation, MHD convective flow, Soret effect, Chemical reaction, Thermal radiation.*

List of Symbols

B_0	constant applied magnetic field
C_f	skin friction coefficient
N	heat radiation parameter
K	permeability parameter
k	permeability of porous medium
M	dimensionless magnetic parameter
N_u	local Nusselt number
N_{ur}	reduced Nusselt number
p_r	prandtl number
q_r	radiative heat flux
q_w	heat flux from the plate
Ω	dimensional rotational parameter
s	dimensionless suction parameter
S_0	soret number
S_c	schimidt number
s_h	shearwood number
k_l	dimensional chemical reaction parameter
k_r	chemical reaction parameter
H	hall current parameter
D_T	coefficient of thermal molecular diffusivity
D_m	coefficient of chemical molecular diffusivity
C	concentration parameter
C_∞	free stream concentration
C_w	wall concentration
G_r	modified thermal grashof number
G_m	modified solutal grashof number
T	local temperature of the nano fluid
T_w	wall temperature of the nano fluid
T_∞	temperature of the ambient nanofluid
U_0	characteristic velocity
w_o	normal velocity
(x, z)	Cartesian coordinates
(u, v, w)	velocity components along x, y axes and z axes.

Greek Symbols

φ	solid volume fraction of the nano particles
α	thermal diffusivity
α_s	thermal diffusivity of the solid
α_f	thermal diffusivity of the fluid
α_{nf}	thermal diffusivity of the nanofluid
β_f	coefficient of thermal expansion of the fluid
β_s	coefficient of thermal expansion of the solid
β_{nf}	coefficient of thermal expansion of the nanofluid
ν	kinematic viscosity
ν_f	kinematic viscosity of the fluid
ρ_f	density of the fluid friction
ρ_s	density of the solid
ρ_{nf}	density of the nanofluid
μ_f	dynamic viscosity of the fluid
μ_s	dynamic viscosity of the solid
μ_{nf}	dynamic viscosity of the nanofluid
ω	dimensionless frequency of oscillation
σ	Electrical conductivity
θ	dimensionless temperature
ϵ	dimensionless small quantity
τ_w	skin friction or shear stress

1. Introduction

In recent years, nanofluids have attracted increased interest owing to their fascinating properties. The term nano fluid was first introduced by Choi (1995) at the A.N.L., USA to depict a liquid suspension containing ultra-fine particles. Nanotechnology is considered to be one of the significant forces that would drive the next major industrial revolution of the new century. It represents the most relevant technological cutting edge currently being explored. It aims at manipulating the structure of the matter at the molecular level with the goal for innovation in virtually every industry and public endeavour including all the various branches of science like biological sciences, physical sciences, chemical sciences, electronics cooling, transportation, environment and national security. Since ultra high performance cooling is one of the most vital needs of many industrial technologies, the nanofluid has found its place as coolants.

Due to the effect of magnetic field in a rotating frame of reference, the study of MHD flow and heat transfer has attracted the interest of many investigators in view of its application in many industrial, astrophysical (dealing with sunspot development, the solar cycle and the structure of a rotating magnetic stars), technological and engineering applications (MHD generators, ion propulsion, MHD pumps etc.) and many other practical applications, such as bio mechanical problems (like blood flow in the pulmonary alveolar sheet). Many authors have studied the flow and heat transfer in a rotating system with various geometrical situations. Hamad (2011) investigated the effect of transverse magnetic field on a free convection flow of a nanofluid past a vertical semi infinite flate plate. Sugunamma and Sandeep (2011) studied MHD radiative flow in porous medium with constant heat flux. Ganji and Malvandi (2014) investigated natural convection of nanofluids inside a vertical enclosure in the presence of a uniform magnetic field. Singh and Alphonsa (2015) analyzed the effect of Heat transfer in viscous free convective fluctuating MHD flow past a hot vertical porous plate with variable temperature. Some other related works can also be found in recent papers by Venkateswarlu et al. (2015) and Venkateswarlu and Satya Narayana (2015).

There are numerous important engineering and geo-physical applications of flows through porous medium, mainly in the fields of geothermal energy recovery, crude oil extraction, storage of radioactive nuclear waste, fiber insulation, etc. Chamka et al. (2011) have also analysed recently the natural convection past a sphere embedded in a porous medium saturated by a nanofluid. Reddy et al. (2013) analysed the effect of unsteady MHD radiative and chemically reactive free convection flow near a moving vertical plate in porous medium. Combined effect of convective nano fluid through a perpendicular plate with dripped porous medium is solved numerically by Kumari et al. (2012). Uddin and Harmand (2013) too have investigated the influence of natural convection heat transfer effects of nanofluids along a vertical plate in porous medium.

The study of heat transfer with chemical reaction in the presence of nanofluids is of immense realistic significance to engineers and scientists, because of its almost universal incidence in many branches of science and engineering (Das 2007). This phenomenon plays an important role in chemical industry, power and cooling industry for drying, evaporation, energy transfer in a cooling tower and the flow in a desert cooler, chemical vapour deposition on surfaces, cooling of nuclear reactors and petroleum industries. In addition, there are many transport processes that are governed by the joint action of the buoyancy forces from both thermal and mass diffusion in the presence of chemical reaction effects. The effect of chemical reaction with heat radiation in the presence of nanofluid over a porous vertical stretching surface is investigated by Rosmila Abdul-Kahar et al. (2011). Kameswaran et al. (2012) have analyzed the hydromagnetic nanofluid flow due to a stretching or shrinking sheet with viscous dissipation and chemical reaction effects. Malvandi, et al. (2014) made an analytical study on boundary layer flow and heat transfer of nanofluid induced by a non-linearly stretching sheet. Recently, many researchers (Ellahi 2013, Ellahi et al. 2013, Narahari et al. 2013, Umavathi 2013) have studied the flow and heat transfer characteristic of Newtonian/non-Newtonian nanofluids over various geometries.

As the various studies indicate, (Xuan and Li 2000, Wang and Mujumdar 2007) there is remarkable heat transfer enhancement when nanofluids are used as coolants instead of ordinary fluids. It was made clear that nanofluids have higher thermal conductivities than ordinary fluids which make them efficient coolants. In the past few years, there are several papers on nanofluid past a wedge, for example, papers by Kasmani et al. (2013), Chamkha et al. (2012), Yacob et al. (2011), Gorla et al. (2011) and Khan and Pop (2013). Theoretical analysis of nanofluid flow of heat transfer in the presence of dufour effects was discussed by Hussein and Mahmood (2012). They noticed that nanoparticles are passed from hot wall to cold wall in the effect of positive thermophoresis parameter and Dofour effect. Alphonsa and Singh (2015) studied the Hall current effect on radiating span-wise fluctuating MHD convective flow through porous medium in a vertical porous channel. And recently the researchers Hamad and Pop (2015) and Raju et al. (2015) examined the effects of various parameters of convective nanofluid flow through porous medium.

To the authors knowledge, no studies have been reported on combined effect of rotation and hall current on unsteady MHD convective nano fluid flow through porous medium past a plate with soret effect, chemical reaction and thermal radiation by considering copper water nano fluid and alumina water nano fluids. Through an appropriate similarity transformation, the governing partial differential equations are reduced into ordinary differential equations, which are then solved using MATLAB. The effects of non-dimensional governing parameters namely volume fraction of the nano particles, hall current parameter, rotation parameter, magneticfield parameter, radiation parameter, Chemical reaction parameter, soret number, buoyancy parameter and porosity parameter on the flow, velocity, temperature and concentration profiles are discussed and presented graphically. Besides, the friction factor, Nusselt number and Sherwood numbers are discussed for two nanofluids.

2. Mathematical Formulation of the Problem

Consider an unsteady three-dimensional incompressible and electrically conducting free convective flow of a nanofluid past a plate in the presence of applied magnetic field with chemical reaction and soret effect. We consider a Cartesian coordinate system (x^*, y^*, z^*). The flow is assumed to be in the x^* direction, which is taken along the plate, and z^* axis normal to the plate. Also it is assumed the whole system is rotating with a constant vector Ω about the z^* axis. The fluid is assumed to be a gray, absorbing, emitting but not a scattering medium. The radiation heat flux in the x^* direction is considered negligible in comparison with that in the z^* direction. A uniform external magnetic field B_0 is taken to be acting along the z^*. The value of this uniform magnetic field is assumed to be unaltered by making the necessary assumptions that guarantee the neglecting of the induced electric and magnetic fields. Electrical and polarization effects are also neglected. Since the plates are infinite in extent, all the physical quantities except the pressure, depend only on z^* and t^*. Denoting the velocity components u^*, v^*, w^* in the x^*, y^*, z^* directions respectively and temperature by T^* and Concentration by C^*, the flow in the rotating system is governed by the following equations:

$$w_z^* = 0 \Rightarrow w^* = -w_0 \tag{1}$$

$$u_t^* - w_0 w_z^* - 2\Omega^* v^* = \frac{1}{\rho_{nf}} \begin{pmatrix} -p_x^* + \mu_{nf} u_{zz}^* + (\rho\beta)_{nf} g(C^* - C_\infty) + (\rho\beta)_{nf} g(T^* - T_\infty) \\ -\mu_f \frac{u^*}{k^*} + \frac{\sigma B_0^2 (Hv^* - u^*)}{(1+H^2)} \end{pmatrix} \tag{2}$$

$$v_t^* - w_0 v_z^* + 2\Omega^* u^* = \frac{1}{\rho_{nf}} \left(-p_y^* + \mu_{nf} v_{zz}^* - \mu_f \frac{v^*}{k^*} - \frac{\sigma B_0^2 (v^* + Hu^*)}{(1 + H^2)} \right) \tag{3}$$

$$T^* - w_0 T_z^* = \alpha_{nf} T_{zz}^* + \frac{1}{(\rho C_p)_{nf}} q r_z^* \tag{4}$$

$$C_t^* - w_0 C_z^* = D_B C_{zz}^* + D_T T_{zz}^* - K_r (C^* - C_\infty). \tag{5}$$

With the boundary conditions:

$$z^* = 0, u^* = v^* = 0, T^* = T_w + \epsilon(T_w - T_\infty)e^{i\omega^* t^*}, C^* = C_w + \epsilon(C_w - C_\infty)e^{i\omega^* t^*}$$

$$z^* \to \infty, u^* = U^*(t^*) = U_0(1 + \epsilon e^{i\omega^* t^*}), T^* = T_\infty, C^* = C_\infty, \nu^* = 0 \tag{6}$$

where ν is the Kinematic viscosity, t is the time, ρ is the density and p^* is the modified pressure, σ is the electric conductivity, C^* Concentration, T^* is the temperature, C_p is the specific heat at constant pressure, k is the thermal conductivity, g is the acceleration due to gravity, β is the coefficient of volume expansion and S^* is the source/sink term. where ω^* is the frequency of oscillations and ϵ is a very small positive constant. The nano fluid constants are given by

$$(\rho\beta)_{nf} = (1-\varphi)(\rho\beta)_f + \varphi(\rho\beta)_s, (\rho C_p)_{nf} = (1-\varphi)(\rho C_p)_f + \varphi(\rho C_p)_s,$$

$$\rho_{nf} = (1-\varphi)\rho_f + \varphi\rho_s, \mu_{nf} = \frac{\mu_f}{(1-\varphi)^{2.5}}, \alpha_{nf} = \frac{k_{nf}}{(\rho C_p)_{nf}}, k_{nf} = k_f \left\{ \frac{k_s + 2k_f - 2\varphi(k_f - k_s)}{k_s + 2k_f + 2\varphi(k_f - k_s} \right\},$$

$$A_1 = (1-\varphi)^{2.5}, A_2 = \left[\frac{k_{nf}}{kf} + \frac{4N}{3} \right], A_3 = 1-\varphi+\varphi\frac{\rho_s}{\rho_f}, A_4 = 1-\varphi+\varphi\frac{(\rho\beta)_s}{(\rho\beta)_f}, A_5 = 1-\varphi+\varphi\frac{(\rho C_p)_s}{(\rho C_p)_f}.$$

By Introducing the following non-dimensional quantities and eliminating the pressure gradient

$$u^* = uU_0, v^* = vU_0, z^* = \frac{zv_f}{U_0}, t^* = \frac{tv_f}{U_0^2}, U = \frac{u^*}{U_0}, \Omega = \frac{\Omega^* v_f}{U_0^2}, S = \frac{w_0}{U_0}, \omega^* = \frac{\omega U_0^2}{v_f},$$

$$\theta = \frac{T^* - T_\infty}{T_w - T_\infty}, M^2 = \frac{B_)^2 \sigma v_f}{\rho_f U_0^2}, \alpha = \frac{s^* d^2}{k}, S_c = \frac{v_f}{D}, G_r = \frac{v_f g\beta_f(T_w - T_\infty)}{U_0^3}, S_0 = \frac{D_T}{v_f},$$

$$G_m = \frac{v_f g\beta_f(C_w - C_\infty)}{U_0^3}, P_r = \frac{v_f(\rho C_p)_f}{k_f}, C = \frac{C^* - C_\infty}{C_w - C_\infty}, K_r = \frac{K_l v_f}{U_0^2}, N = \frac{4\sigma^* T_\infty^{*^3}}{k_f k^*}$$

and suppressing the stars '$*$', the equations (2) to (4) become

$$\omega q_t - sq_z + 2\Omega i(q-U) = U_t + \frac{1}{A_1 A_3} q_{zz} + \frac{1}{A_3 k}(U-q) + \frac{M^2(Hi-1)}{A_3(1+H^2)}(q-U) + \frac{A_4}{A_3}(G_m C + G_r\theta) \tag{7}$$

$$\theta_t - S\theta_z = \frac{A_2}{A_5 P_r}\theta_{zz} \tag{8}$$

$$C_t = SC_z = \frac{1}{S_C} C_{zz} + S_0\theta_{zz} - K_r C \tag{9}$$

wjere $q = u + iv$.

The boundary conditions (6) can also be written in complex notations as

$$\left.\begin{aligned} &z = 0, q = 0, \theta = C = 1 + \epsilon e^{i\omega t}, \\ &z \to \infty, \theta = C = 0, q = 1 + \epsilon e^{i\omega t}, . \end{aligned}\right\} \tag{10}$$

In order to solve the system of equations (7), (8) and (9) subject to the boundary conditions (10), we assume,

$$\left.\begin{aligned} q(z,t) &= (1 - q_0) + \epsilon(1 - q_1)e^{i\omega t} + 0(\epsilon^2), \\ \theta(z,t) &= \theta_0(z) + \epsilon\theta_1(z)e^{i\omega t} + 0(\epsilon^2), \\ C(z,t) &= C_0(z) + \epsilon C_1(z)e^{i\omega t} + 0(\epsilon^2). \end{aligned}\right\} \tag{11}$$

The solution of the equations (7), (8) and (9) under the boundary condition (10) is as follows

$$\begin{aligned} q(z,t) &= (1 - e^{-n5z} + (p_3 + p_5)(e^{-n3z} - e^{-n5z}) + (p_4 + p_6)(e^{-n1z} - e^{-n5z})) \\ &\quad + \epsilon 1 - e^{-n6z} + (p_7 + p_9)(e^{-n4z} - e^{-n6z}) + (p_8 + p_{10})(e^{-n2z} - e^{-n6z})e^{i\omega t} \end{aligned} \tag{12}$$

$$\theta(z,t) = e^{-n1z} + \epsilon e^{-n2z}e^{i\omega t} \tag{13}$$

$$C(z,t) = e^{-n3z} + p_1(e^{-n1z} = e^{-n3z}) + \epsilon(e^{-n4z} + p_2(e^{-n2z} - e^{-n4z}))e^{i\omega t}. \tag{14}$$

The physical quantities of interest are the skin friction coefficient, Nusselt number and Sherwood number which are respectively defined as

$$C_f = \frac{\overline{\tau}_w}{\rho_f U_0^2}, \quad Nu = \frac{\overline{xq}_w}{k_f(T_w - T_\infty)}, \quad Sh = \frac{\overline{xq}_m}{D_B(C_w - C_\infty)}$$

where $\overline{\tau}_w, \overline{q}_w$ and $\overline{q}_m$ are the wall shear stress , the wall heat flux from the plate and the wall mass flux from the plate respectively, which are given by

$$\overline{\tau} = \mu_{nf}\left(\frac{\partial \overline{u}}{\partial \overline{z}}\right)_{\overline{z}=0}, \quad \overline{q}_w = -k_{nf}\left(\frac{\partial T}{\partial \overline{z}}\right)_{\overline{z}=0}, \quad \overline{q}_m = -D_B\left(\frac{\partial C}{\partial \overline{z}}\right)_{\overline{z}=0}.$$

Using non-dimensional quantities we obtain $C_f = \frac{1}{(1-\varphi)^{2.5}}q'(0)$, $N_{ur} = -\frac{k_{nf}}{k_f}\theta'(0)$ and $Sh_r = -C'(0)$, where $N_{ur} = \frac{Nu}{Re_x}$ and $Sh_r = \frac{Sh}{Re_x}$ and $Re_x = \frac{U_0\overline{x}}{v_f}$ is the local Reynolds number. N_{ur} and Sh_r are the reduced Nusselt number and reduced Sherwood Number respectively.

2. Results and Discussion

A theoretical study on the effect of the metallic nanoparticles on unsteady MHD convective nano fluid flow through porous medium past a plate with soret effect, chemical reaction and thermal radiation when the plate oscillates in the time t in the presence of hall effect and rotating frame of reference has been performed in this paper. The effect of nanoparticles on the velocity, temperature and concentration profiles as well as on the skin friction coefficient, Nusselt number and Sherwood number are discussed numerically. We have chosen here $\omega = 10$, $t = \frac{\pi}{2}$, $p_r = 6.72$, $\epsilon = 0.02$, $K = 0.5$, $N = 1$, $k_r = 1$, $Gr = 0.5$, $Gm = 0.5$, $\Omega = 5$, $S_0 = 1$, $S = 0.5$, $H = 0.5$, $S_c = 0.16$, $M = 2$, $\varphi = 0.1$ for the numerical results. These values are kept common in entire study except the valuesvaried in respective figures. The thermo-physical properties of the base fluid (water), copper and Alumina were used for code validation and are given in Table 1.

Table 1 : Thermo Physical properties of base fluid and different nanoparticles

Physical Properties	Water	Cu	Al_2O_3
$C_p(j/kgK)$	4179	385	765
$\rho(kg/m^3)$	997.1	8933	3970
$K(W/mK)$	0.613	400	40
$\beta \times 10^{-5}(1/K)$	21	1.67	0.85

Fig. 1 depicts the effect of volume fraction of nano particles (φ) on velocity profiles for $Cu-water$ and $Al_2O_3-water$ nanofluids. It is observed that as the volume fraction (φ) increases, the velocity decreases for both the nano fluids. In Fig.2, the effect of volume fraction of nano particles (φ) on temperature profiles for $Cu-water$ and $Al_2O_3-water$ nanofluids is depicted. It is clear from the figure that the temperature increases as the volume fraction increases. In the case of temperature profiles, $Cu-water$ and $Al_2O_3-water$ nanofluids have the same values. These figures illustrate this agreement with the physical behaviour. When the volume of the nanoparticles increases, the thermal boundary layer thickness increases. We also observe that the velocity distribution in $Cu-water$ nano fluid is higher than $Al_2O_3-water$ nanofluid.

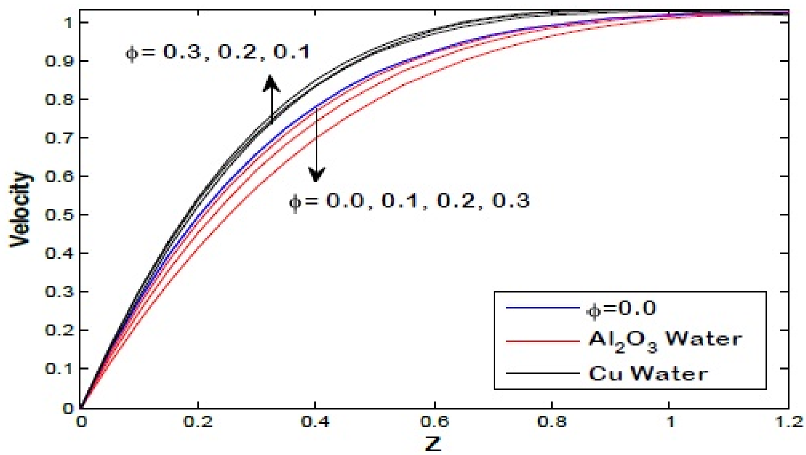

Fig.1 Velocity profile for different values of φ

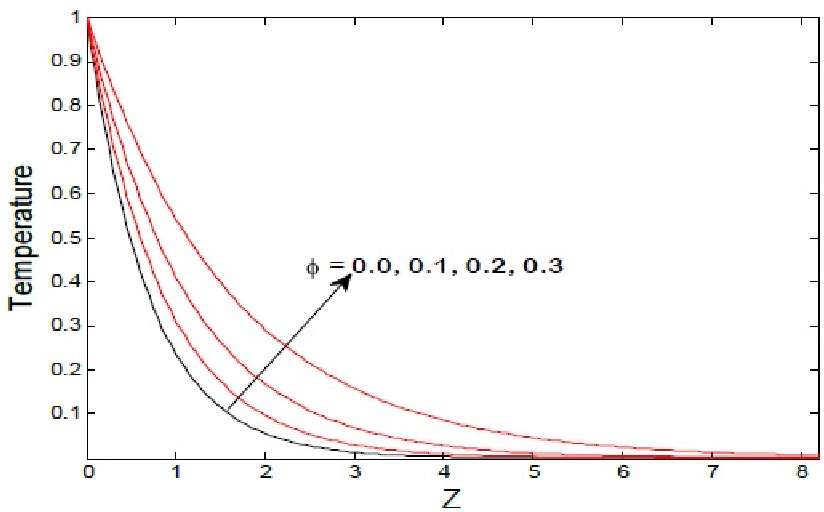

Fig.2 Temperature profile for different values of φ

Fig. 3 and 4 illustrate the effect of heat radiation parameter on temperature and concentration respectively. It is clear that the temperature increase as N increases. Physically an increase in the radiation releases heat to the flow, which helps to enhance the velocity and thermal boundary layer thickness. Therefore, N depreciates the concentration profile.

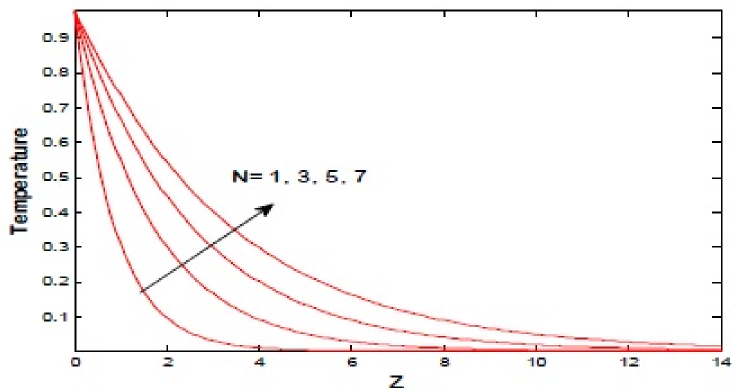

Fig.3 Temperature profile for different values of N

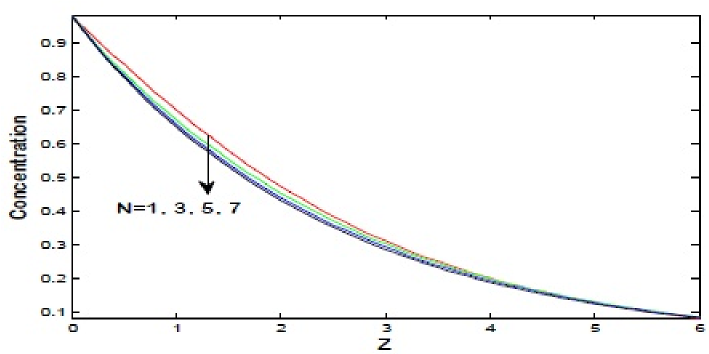

Fig.4 Concentration profile for different values of N

Fig. 5 and 6 show that the effect of soret number on velocity and concentration profile. From the figures, it is clear that as increases the velocity decreases for both nanofluids. But it will be reverse in the case of concentration. Increase in the soret number leads to an increase in the fluid flow which causes the momentum boundary layer thickness, which in turn, generally increases away from the plate satisfying the boundary conditions. As soret number increases, the concentration boundary layer thickness of the nanofluid also increases.

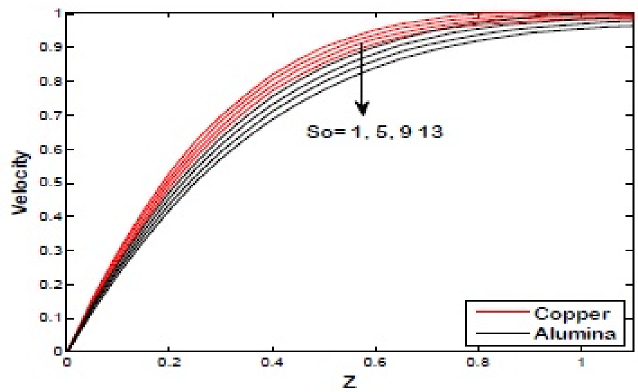

Fig.5. Velocity profile for different values of S_0

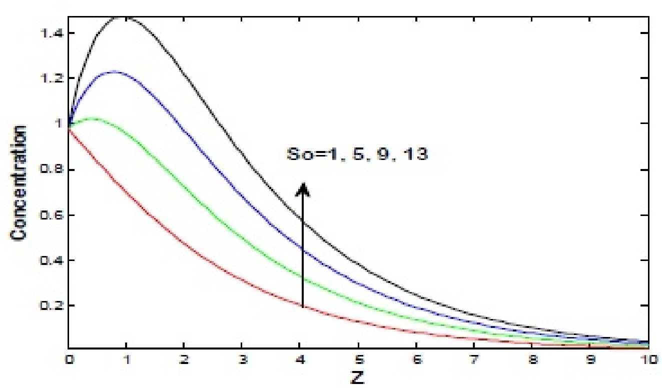

Fig. 6 Concentration profile for different values of S_0 for Cu-water

Fig. 7 depict the variation with respect to Hall parameter H ($Cuwater$ and $Al_2O_3 - water$) for the velocity. An increase in the Hall parameter (H) leads to a slight drop in the velocity profile. This is due to the minimal retarding force along the y direction created between the interaction of the applied magnetic field and the field due to the hall current.

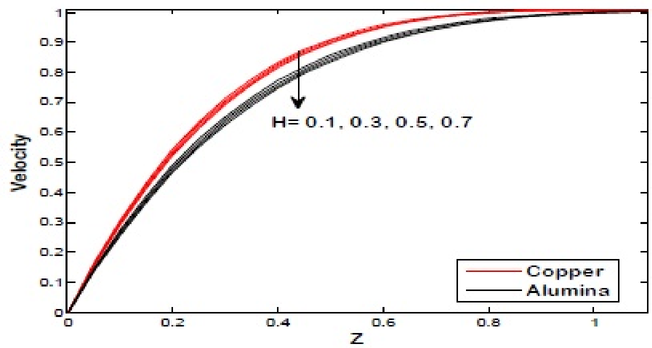

Fig. 7 Velocity profile for different values of H

Fig. 8, 9 and 10 show the velocity profile for different values of G_r, G_m and Ω. From the figures, it is clear that the velocity increases with increase of all the three parameters. Thermal Grashof number G_r leads to an increase in the velocity due to the enhancement in buoyancy forces. Actually, the thermal Grashof number signifies the relative importance of buoyancy force to the viscous hydrodynamic force. Increase of Grashof number G_r indicates small viscous effects in the momentum equation and consequently, causes increase in the velocity profiles. The velocity increases with increasing G_m in a similar manner as we noticed in the case of G_r. The modified Grashof number G_m defines the ratio of the species buoyancy force to the viscous hydrodynamic force. It is also noticed that velocity of $Cu-water$ nanofluid increases more than that of $Al_2O_3-water$ nanofluid.

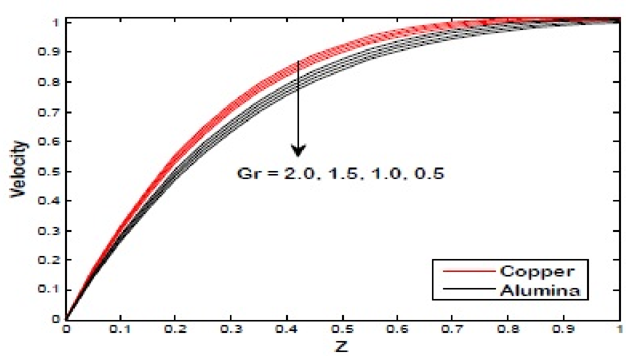

Fig. 8 Velocity profile for different values of G_r

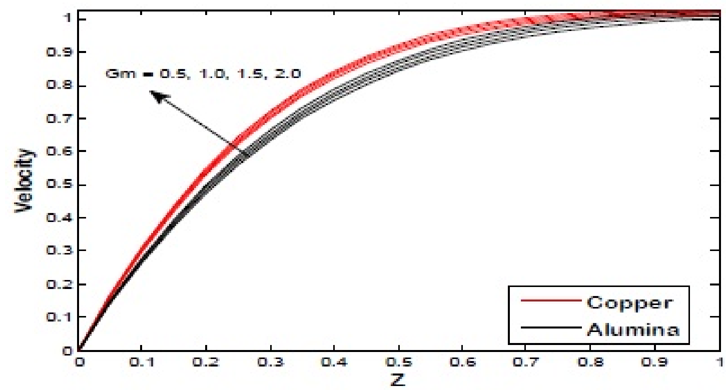

Fig. 9 Velocity profile for different values of G_m

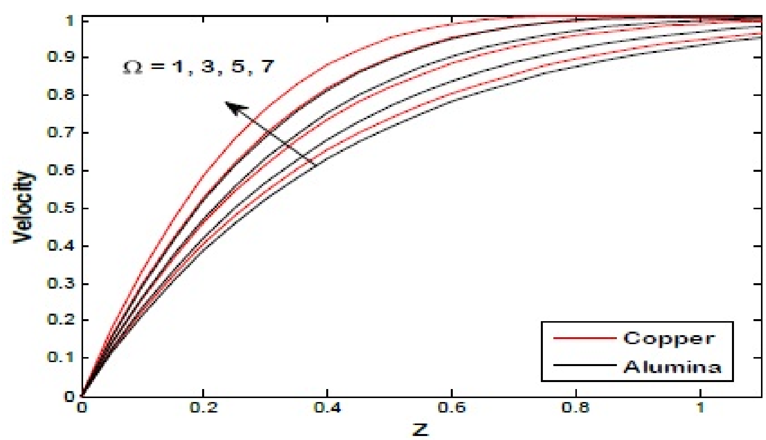

Fig. 10 Velocity profile for different values of Ω

Fig. 11 shows the effect of chemical reaction parameter k_r declines the concentration profile. Physically, for a destructive case ($k_r > 0$), chemical reactions take place with many disturbances. This turn causes high molecular motion which results in an increase in the transport phenomenon, thereby reducing the concentration distributions in the fluid flow.

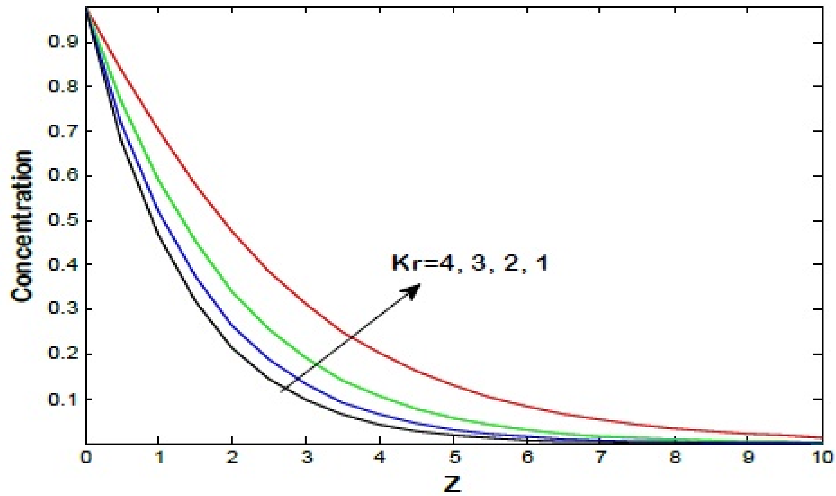

Fig.11 Concentration profile for different values of K_r

Fig.12 and 13 depict the effect of Schmidt number S_c on velocity and concentration. From the figure, it is clear that a raise in the value of S_c depreciates the velocity and concentration profile. The Schmidt number quantifies the relative effectiveness of momentum and mass transport by diffusion in the velocity and concentration boundary layers. As the Schmidt number increases the concentration decreases. This causes the concentration buoyancy effects to decrease yielding a reduction in the fluid velocity. The reduction in the velocity and concentration profiles are accompanied by simultaneous reductions in the velocity and concentration boundary layers.

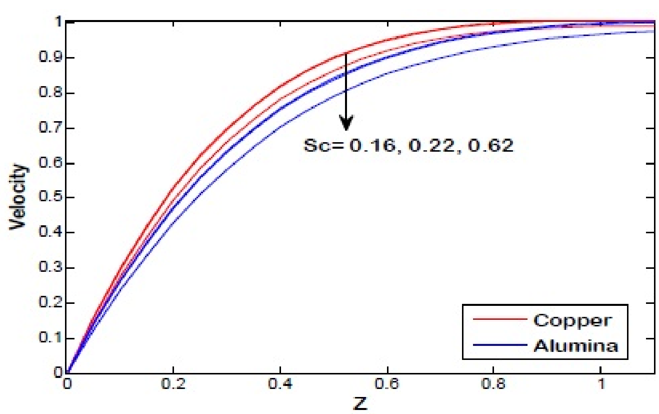

Fig.12 Velocity profile for different values of S_c

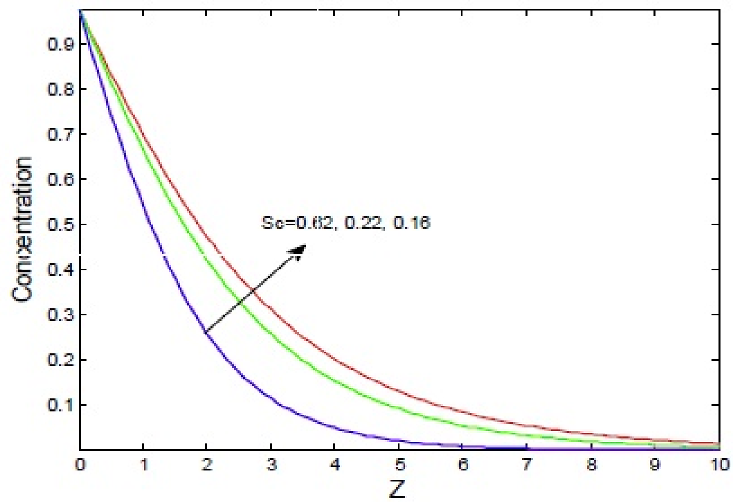

Fig.13 Concentration profile for different values of S_c

Fig.14 depicts the variation of skin friction coefficient (C_f), with respect to suction parameter for different values of volume fraction. It is observed that skin friction decreases with increase of volume fraction of nano particles. It is seen that suction parameter S depreciates the friction factor.

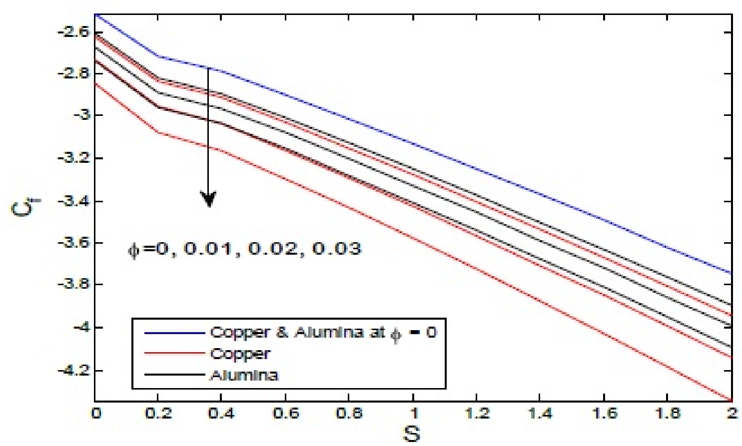

Fig. 14Skin friction for different values of φ with respect to S

Fig. 15 illustrates the variation of the heat transfer rate or Reduced Nusselt number (Nu_r) for $Cu-water$ and $Al_2O_3-water$ nanofluids with suction parameter for various values of volume fraction of nano particles φ. It is evident from the figure 21 that increase in the volume fraction of nano particles φ, suction parameter S enhances the heat transfer rate.

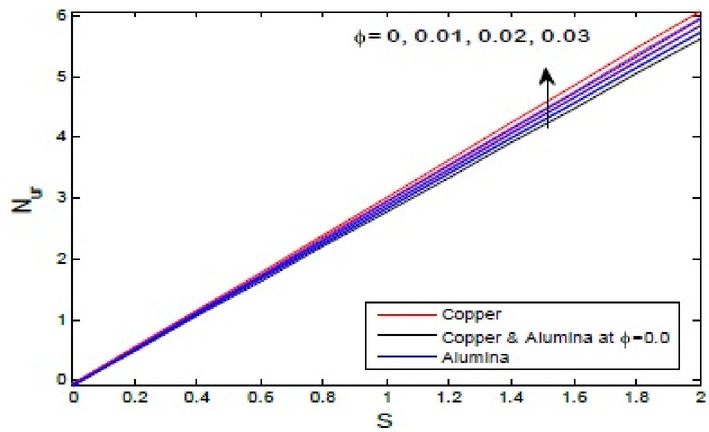

Fig.15 Nusselt for different values of φ with respect to *S*

Fig. 16, depicts mass transfer for different values of φ with respect to S_0 (soret number). It is clear from the figure that increase in the volume fraction of nano particles φ enhances the mass transfer rate. It can also be noticed that increase in the Soret number (S_0) depreciate the mass transfer rate with

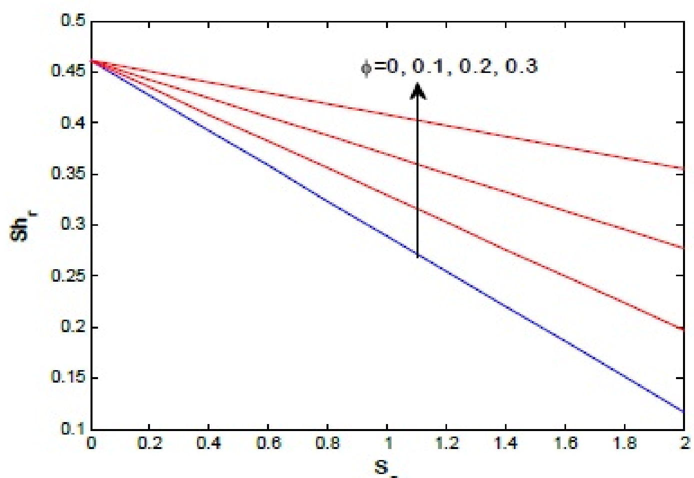

Fig.16 Sherwood number for different values of φ with respect to S_0

4. Conclusions

In the present study, we have theoretically studied the effects of the mettalic nano particles on Unsteady MHD Convective Nano Fluid Flow through Porous Medium past a plate with Soret effect, Chemical Reaction and Thermal Radiation in the presence of Combined effects of Hall Current and Rotation. We have investigated the way in which the velocity temperature and concentration profiles as well as the surface skin friction, surface heat flux and surface mass flux depend on the nano particles volume fraction parameter. It is shown that the inclusion of the nano particles in to the base fluid is capable to change the flow pattern for the problem under consideration. Significant findings are as follows

- Velocity distribution $Cu - water$ in nano fluid is higher than $Al_2O_3 - water$ nanofluid.
- When the volume of the nanoparticles increases, the thermal boundary layer thickness increases. But reverse in the case of concentration.
- The temperature increase as the radiation parameter N increases. Physically an increase in the radiation releases heat to the flow, which helps to enhance the velocity and thermal boundary layer thickness. Therefore, N depreciates the concentration profile.
- As S_0 increases the velocity decreases for both nanofluids. But it will be reverse in the case of concentration.
- An increase in the Hall parameter (H) leads to a slight drop in the velocity profile.
- Velocity increases with increase of all the three parameters G_r, G_m and Ω.
- Chemical reaction parameter k_r declines the concentration profile.
- A raise in the value of Schmidt number S_c depreciates the velocity and concentration profile.
- Skin friction decreases with increase of volume fraction of nano particles. It is seen that Grashof number G_r and permeability parameter K enhance the skin friction but suction parameter S depreciates the friction factor.

- Increase in the volume fraction of nano particles φ, the frequency of oscillation parameter ω and suction parameter S enhances the heat transfer rate.
- Depreciate the mass transfer rate with increase of soret number (S_0).

Appendix

$$n_1 = \frac{A_5 PrS}{A_2}, \quad n_2 = \frac{\frac{A_5 PrS}{A_2} + \sqrt{\left(\frac{A_5 PrS}{A_2}\right)^2 + \frac{4A_5 Pri\omega}{A_2}},}{2} \quad n_3 = \frac{S_c S + \sqrt{S_c^2 S^2 + 4S_c K_4}}{2},$$

$$n_4 = \frac{S_c S + \sqrt{S_c^2 S^2 + 4S_c(K_r + i\omega)}}{2}, \quad n_5 = \frac{A_1 A_3 S + \sqrt{(A_1 A_3 S)^2 + 4B_1}}{2}$$

$$n_6 = \frac{A_1 A_3 S + \sqrt{(A_1 A_3 S)^2 + 4B_2}}{2}$$

$$P_1 = \frac{-S_c S_0 n_1^2}{n_1(n_1 - S_c S) - S_c K_r}, \quad P_2 = \frac{-S_c S_0 n_2^2}{n_2(n_2 - S_c S) - S_c(K_r + i\omega)},$$

$$P_3 = \frac{A_1 A_4 G_m}{n_3(n_3 - A_1 A_3 S) - B_1}, \quad P_4 = \frac{A_1 A_4 G_m P_1}{n_1(n_1 - A_1 A_3 S) - B_1},$$

$$P_5 = \frac{-A_1 A_4 G_m P_1}{n_3(n_3 - A_1 A_3 S) - B_1}, \quad P_6 = \frac{A_1 A_4 G_r}{n_1(n_1 - A_1 A_3 S) - B_1},$$

$$P_7 = \frac{A_1 A_4 G_m}{n_4(n_4 - A_1 A_3 S) - B_2}, \quad P_8 = \frac{A_1 A_4 G_m P_2}{n_2(n_2 - A_1 A_3 S) - B_2},$$

$$P_9 = \frac{-A_1 A_4 G_m P_2}{n_4(n_4 - A_1 A_3 S) - B_2}, \quad P_{10} = \frac{A_1 A_4 G_r}{n_2(n_2 - A_1 A_3 S) - B_2},$$

$$B_1 = 2\Omega i A_1 A_3 + \frac{A_1}{K} - \frac{M_2 A_1(Hi - 1)}{(1 + H^2)}, \quad B_2 = (2\Omega + \omega) i A_1 A_3 + \frac{A_1}{K} - \frac{M^2 A_1(Hi - 1)}{(1 + H^2)}$$

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