Numerical simulation for convective heat and mass transfer effect of micropolar nanofluid flow with Variable Viscosity and radiation

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Abstract:- The present work gives out the heat and mass transfer effect of micropolar nanofluid flow. The fluid viscosity is assumed as temperature dependent and it varies linearly. The radiative heat flux **and** the viscous dissipation are also considered in the energy equation. The partial differential equations governing the flow have been transformed into system of ordinary differential equation and explained numerically through fourth order Runge-Kutta method with shooting technique. Fluid properties such as velocity, angular velocity, temperature, and concentration are analyzed graphically for a range of solid volume fraction ($0<\phi<2$) of nano-solid particles.

Keywords:- Nano fluid, Forced convection, Boundary layer, Micropolar, heat and mass transfer.

Received: January 27, 2021. Revised: April 5, 2021. Accepted: April 8, 2021. Published: April 13, 2021.

1. Introduction

In recent years there is a significant growth in the use of colloids manufactured by Nano sized particles disseminated in a base fluid. Choi [1] invented nano fluid and these concocted colloids have an application in several field such as Nuclear Reactors, Extraction of Geothermal Power and Other Energy Sources, Automotive Applications, Electronic Applications, Microscale Fluidic Applications such as micro electromechanical systems (MEMS), nano electromechanical systems (NEMS) [3]. Widely used, Conventional fluids in heat exchange devices like alcohol, water, oil, glycol ethylene, have relatively low thermal conductivity coefficient.
From earlier research, shows that nanofluids have the ability to enhanced thermophysical properties such as thermal conductivity, thermal diffusivity, viscosity and convective heat transfer coefficients compared to those of base fluids like oil or water. [4–6] Yu, W., France at.el [2] provided the excellent review on current status of nanofluid technology for heat transfer applications.

Also most recent progress in many engineering developments such as extrusion of polymer and plastic sheets, process of crystal growth, etc. brands a flow of micropolar fluid in the boundary layer on a constantly moving surface as an important area of research. The theory of micropolar fluid was first instigated by Eringen [6]. Micropolar fluid contains rigid, randomly oriented particles dispersed in a viscous medium. Some examples of such fluids are liquid crystals, animal fluid, and some polymeric fluids. Later, many studies have examined the effect of heat transfer of micropolar fluid past continuously moving plate [7,8,9].

Combined effect in moving fluid with radiation is also important in view of several physical problems. Loganathan and Golden Stepha [7],[8] considered the problem on heat and mass transfer effects of forced convective flow of micropolar fluid in the presence of radiation.
The current research aims to examine theoretically the effect of heat and mass transfer on micropolar model for nanofluidic suspensions.

2. Problem formulation:

A flow of steady, two-dimensional, incompressible, heat and mass transfer flow on a continuously moving flat porous plate with a constant velocity in a water based nanofluids containing different nano particles such as CuO, Al_2O_3 and TiO_2, medium at rest is formulated mathematically. The problem is described in the rectangular coordinate system. The origin of the coordinate system is placed at the place where the plate is drawn into the fluid medium as shown in the Figure 1.1.

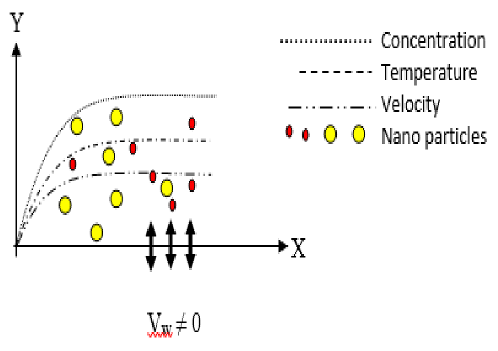

Fig. 1: Flow Model

The x-axis is taken along the plate and y-axis is normal to it. The surface of the plate is maintained at a uniform temperature T_W and a uniform concentration C_W. The fluid is considered to be gray, emitting and absorbing. Heat flux in the x-direction is negligible compared to the flux in the y-direction. The fluid viscosity is assumed as temperature dependent and it varies linearly. The equation of continuity, momentum, angular momentum, energy and concentration in the boundary layer flow are

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \quad (1)$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}=\frac{1}{\rho_{nf}}\frac{\partial}{\partial y}\left(\mu_{nf}+k\right)\frac{\partial u}{\partial y}+\frac{k}{\rho_{nf}}\frac{\partial \sigma}{\partial y} \quad (2)$$

$$\rho_{nf}j\left(u\frac{\partial \sigma}{\partial x}+v\frac{\partial \sigma}{\partial y}\right)=\gamma_{nf}\frac{\partial^2 \sigma}{\partial y^2}-k\left(2\sigma+\frac{\partial u}{\partial y}\right) \quad (3)$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{k_{nf}}{(\rho c_p)_{nf}}\frac{\partial^2 T}{\partial y^2}+\frac{\gamma_{nf}}{c_p}\left(\frac{\partial u}{\partial y}\right)^2-\frac{1}{(\rho c_p)_{nf}}\frac{\partial q_r}{\partial y} \quad (4)$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D\frac{\partial^2 C}{\partial y^2} \quad (5)$$

Subjected to the boundary condition

$$u=U_0, v=V_W, \sigma=-n\frac{\partial u}{\partial y}, T=T_W, C=C_W \ \ as\ y\to 0 \quad (6)$$

$$u=0, v=0, \sigma=0, T=T_\infty, C=C_\infty \ \ as\ y\to\infty$$

where

$\rho_{nf}=(1-\varphi)\rho_f+\varphi\rho_s$

φ- volume fraction of nano-solid particle

ρ_{nf}- density of nano fluid

ρ_s – density of solid particle

ρ_f- density of base fluid

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

$\mu_{nf}=\dfrac{\mu_f}{(1-\varphi)^{25}}$

Now considered the following dimensionless similarity variables

$$\eta=y\sqrt{\frac{U_0}{2\gamma_f x}},\ \psi=\sqrt{2\gamma_f U_0 x}\,f(\eta)$$

$$\sigma=\sqrt{\frac{U_0^3}{2\gamma_f x}}g(\eta),\quad \theta=\frac{T-T_\infty}{T_W-T_\infty},\quad \varphi=\frac{C-C_\infty}{C_W-C_\infty} \quad (7)$$

$$\Pr=\frac{\gamma_f\rho c_\rho}{k},\quad N=\frac{k'k_{nf}}{4\sigma_1 T_\infty^3},\quad Ec=\frac{U_0^2}{c_p(T_W-T_\infty)},$$

$$F_W=-V_W\sqrt{\frac{2x}{\gamma_f U_0}}$$

where $f(\eta)$ and $g(\eta)$ are dimensionless stream functions, in sight of equation (7), equations (2)-(5) are converted to the following system of ordinary differential equations

$$\frac{\left(\frac{\mu_{nf}}{\mu_f}+K\right)}{\left((1-\varphi)+\varphi\frac{\rho_s}{\rho_f}\right)}f'''+ff''+\frac{\gamma_r}{(1-\varphi)^{25}\left((1-\varphi)+\varphi\frac{\rho_s}{\rho_f}\right)}f''\theta'+\frac{K}{\left((1-\varphi)+\varphi\frac{\rho_s}{\rho_f}\right)}g'=0 \quad (8)$$

$$\frac{\left(\frac{\mu_{nf}}{\mu_f}+\frac{K}{2}\right)}{\left((1-\varphi)+\varphi\frac{\rho_s}{\rho_f}\right)}g''-gf'+fg'-\frac{2K}{\left((1-\varphi)+\varphi\frac{\rho_s}{\rho_f}\right)}(2g+f'')=0 \quad (9)$$

$$(3N+4)\theta''+\frac{3NPrEc}{(1-\varphi)^{25}\left((1-\varphi)+\varphi\frac{\rho_s}{\rho_f}\right)}(f'')^2+3NPrf\theta'=0 \quad (10)$$

$$\frac{1}{(1-\varphi)^{25}\left((1-\varphi)+\varphi\frac{\rho_s}{\rho_f}\right)}\lambda''+Sc\,\lambda'f=0 \quad (11)$$

Boundary condition

$$f(0)=F_W, f'(0)=1, g(0)=-nf'', \theta(0)=1, \lambda(0)=1\ as\ \ \eta=0 \quad (12)$$

$$f'(\infty)=0, g(\infty)=0, \theta(\infty)=0, \lambda(\infty)=0\ as\ \ \eta=\infty$$

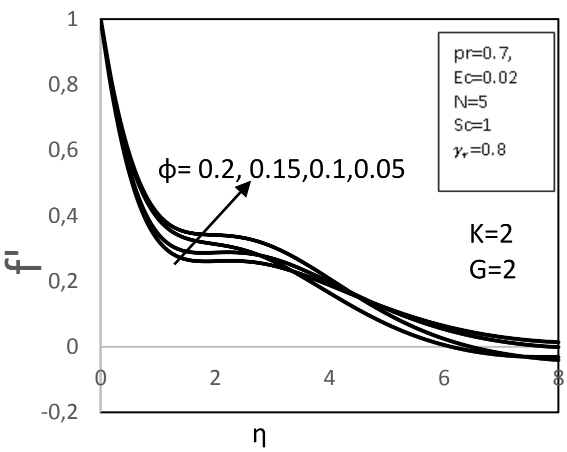

Fig 2: Velocity profile for different φ

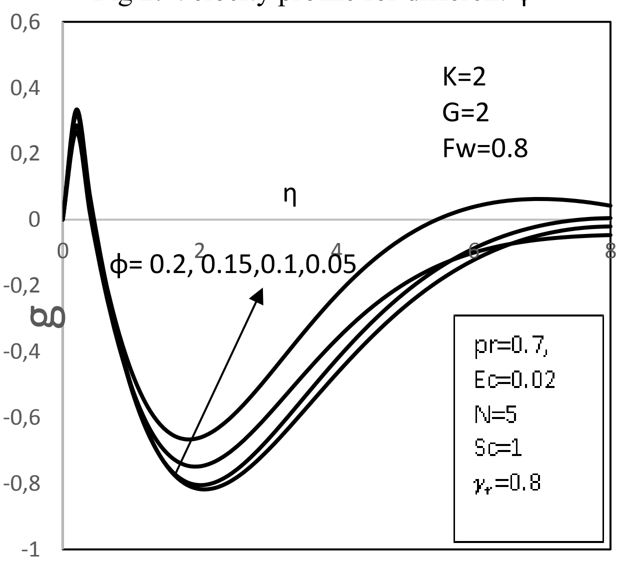

Fig 3. Micro rotation profile for different values of φ

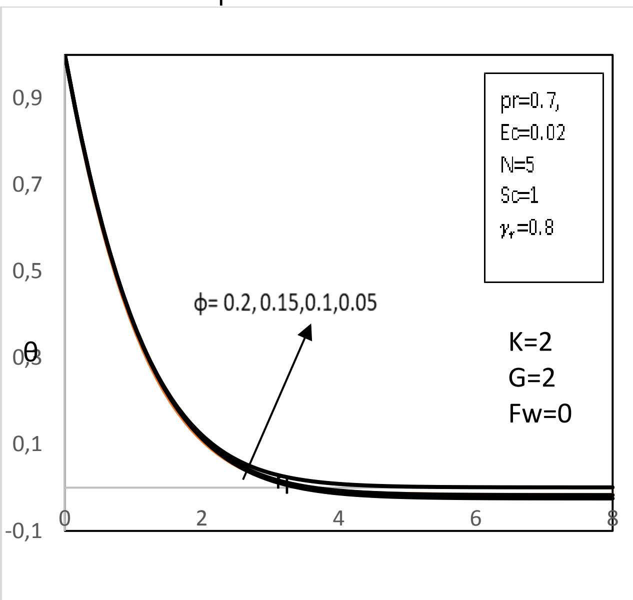

Fig 4. Temperature profile for different values of φ

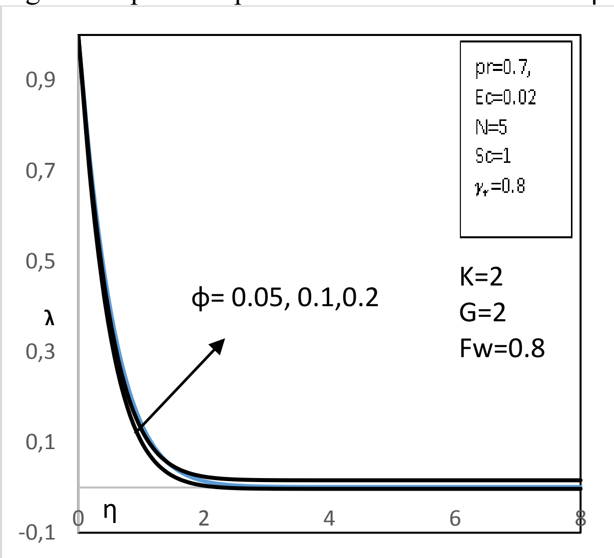

Fig 5. Concentration profile for different values of φ

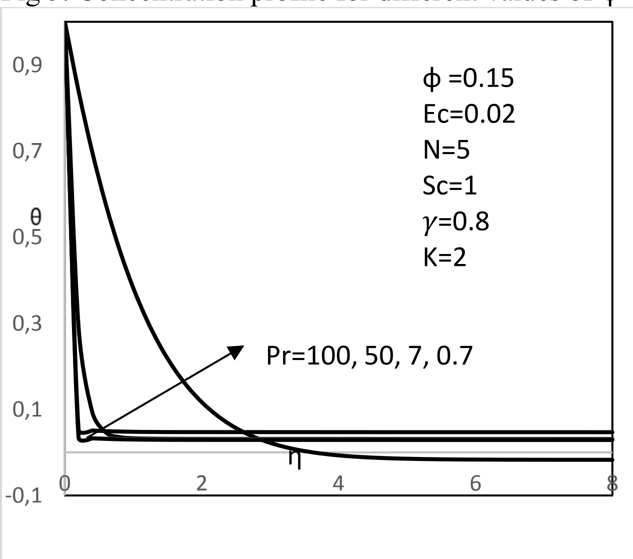

Fig 6. Temperature profile for different values of Pr

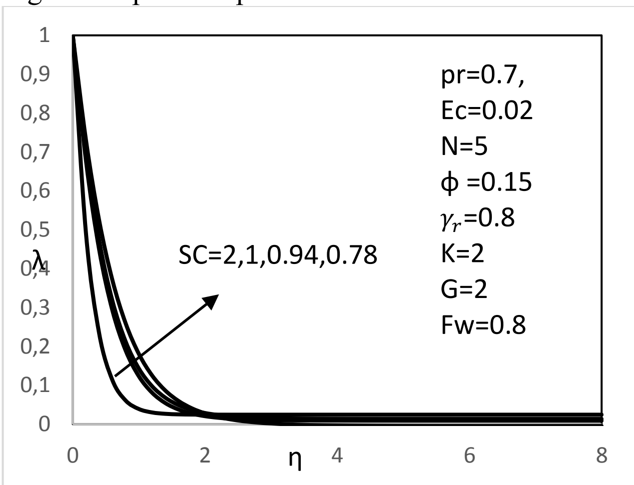

Fig 7. Concentration profile for different values of Sc

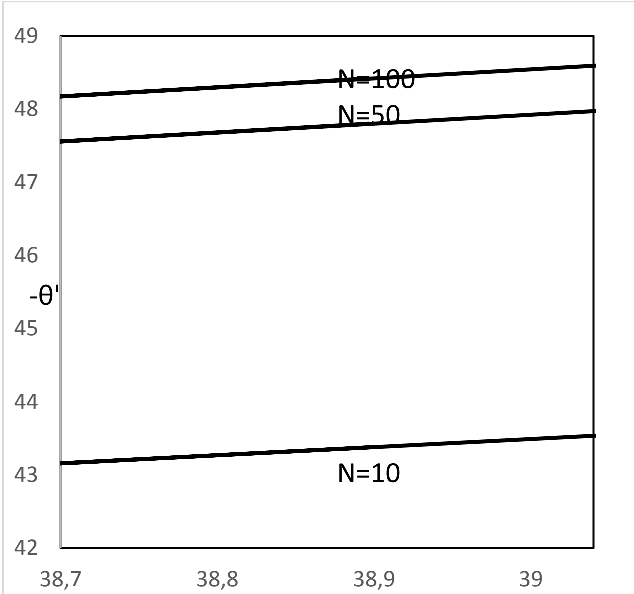

Fig 8.Heat transfer for different value for N

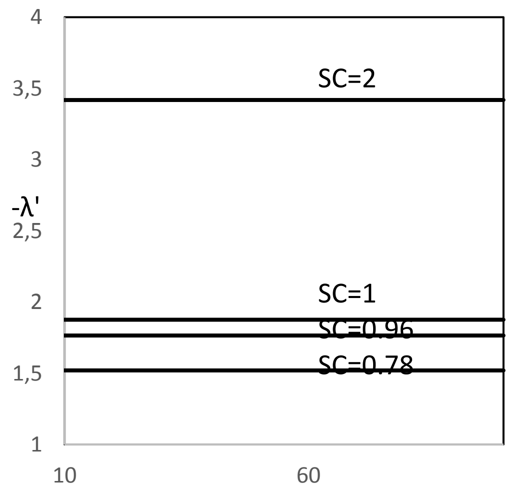

Fig 9: Mass transfer for different value for Sc

3.Numerical Solution

The system of non-linear partial differential equations (1), (2), (3), (4) and (5) with the boundary condition (6) are transformed into ordinary differential equations using similarity transformation.The coupled non-linear ordinary differential equations (7), (8), (9), and (10) with the boundary condition (11) are solved by using fourth order Runge-Kutta method along with Nactsheim–Swigert shooting technique (Adams and Rogers [9]) for the prescribed parameter ϕ, F_w, K, N, Pr, Sc, G, and γ_r. A computer program was set up for the above-mentioned procedure along with fourth order Runge-Kutta method, to solve the equation (7) – (10) with boundary condition (11). A step size of $\Delta\eta$ = 0.01 was selected to satisfy the convergence criterion of 10^{-4} in all cases.

4.Results and Discussion

Solution of the above model is presented as graphs. Fig.2 expresses about the velocity of the micro polar nanofluid in the boundary layer of the flow for various values of volume fraction of nano-solid particle. Fig 2 shows that velocity of the fluid decrease as volume fraction of nano-solid particle increases. The fig.3 displays the angular velocity of the micropolar nano fluid near the boundary layer for different values of volume fraction of nano-solid particle. It observes that the angular velocity of the micropolar nano fluid decreases as ϕ increases. The fig.4 exhibits the temperature distribution of the micro polar nanofluid and it states that slight variation in the temperature of the fluid when volume fraction of nano-solid particle changes. The fig.5 exhibits the concentration distribution of the micro polar nanofluid and it states that slight variation in the concentration of the fluid when volume fraction of nano-solid particle changes. The fig.6 exhibits the temperature distribution of the micro polar nanofluid for various values of Pr and it is observed that the temperature of the fluid decrease as Pr increases. . The fig.7 exhibits the concentration distribution of the micro polar nanofluid for various values of Sc and it is found that the concentration of the fluid decrease as Sc increases. The fig.8 displays the heat transfer profile for various value of radiation parameter N and it is clearly showed that amount of heat transfer is greater for increasing values of radiation parameter. The fig.9 displays the mass transfer profile for various value of Sc and it is clearly showed that amount of mass transfer is greater for higher values of Sc.

5. Conclusion

The numerical investigation has been carried out on the effect of velocity, microrotation, temperature and concentration of the micropolar nanofluid flow within the boundary layer.
Computation is carried out for the prescribed parameters such as volume fraction of nano-solid particle ϕ, radiation parameter N, Prandtl number and Schmidt number. More over the effect of the above mentioned parameters on velocity, temperature and concentration of the fluid within the boundary layer are presented graphically.

Finally it concludes that;

- The velocity of the fluid within the boundary layer decreases when the volume fraction of nano-solid particle ϕ increases.
- The microrotation of the fluid within the boundary layer decreases for increasing value of volume fraction of nano-solid particle ϕ,.
- The temperature decreases due to increase in Prandtl number and concentration declines as the Schmidt number increases.
- The heat transfer parameter increases with the increasing values of Prandtl number while rate of mass transfer decreases with increasing Schmidt number.

Nomenclature

C	species concentration
D	binary diffusion coefficient
N	radiation parameter
T	temperature
q_r	radiative heat flux
C_p	specific heat
E_c	Eckert number
k	thermal conductivity
K_1	coupling constant
G	micro rotation parameter
Pr	Prandtl number
Sc	Schmidt number
f	dimensionless stream function
g	dimensionless micro rotation
u	velocity in x direction
v	velocity in y direction

U_0 velocity of the plate
x distance along the surface
y distance normal to the surface

Greek Symbols
η similarity Variables
μ_f reference viscosity
γ_s spin gradient viscosity
σ micro rotation component
σ_1 Stefan-Boltzmann constant
θ dimensionless temperature
λ dimensionless concentration
ϕ volume fraction of nano-solid particle

Subscripts
W condition on the wall
∞ free stream condition

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