Study on Laminar Incompressible Flow of Nano Fluid over a Circular Sheet With Heat and Mass Transfer

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Abstract-*This paper deals with the laminar incompressible flow of nanofluid over a circular sheet with heat and mass transfer. The model used for nanofluid contains the effects of Brownian motion and thermophoretic diffusion of nanoparticles simultaneously. The recently proposed boundary condition is considered which requires the mass flux of nanoparticles at the wall to be zero. The numerical solutions are obtained by Runge kutta sixth order method. The behavior of Brownian motion on the fluid temperature and wall heat transfer rate plays an important role. Further the nanoparticle volume fraction distribution is found to be negative near the vicinity of the stretching sheet.*

Keywords-*Nanofluid, Brownian motion, axisymmetric flow*

I. Introduction

A nanofluid is a fluid contains nanometer-sized particles, said nanoparticles. These fluids are engineered colloidal suspensions of nanoparticles in a base fluid. The nanoparticles used in nanofluids are typically made of metals, oxides, carbides, or carbon nanotubes. Nano fluids are produced by several techniques they are, Direct Evaporation, Gas condensation/dispersion, Chemical vapour condensation, Chemical precipitation. Nano fluids have novel properties that make them potentially useful in many applications in heat transfer, including microelectronics, petroleum cells, pharmaceutical processes, and hybrid-powered engines, engine cooling/vehicle thermal management, domestic refrigerator, chiller, heat exchanger, in grinding, machining and in boiler tube gas temperature reduction. They exhibit improved thermal conductivity and the convective heat transfer coefficient compared to the base fluid. Nanofluids are primarily used for their improved thermal properties as coolants in heat transfer equipment such as heat exchangers, electronic cooling system and radiators. Heat transfer over flat plate has been analyzed by many researchers. Researchers have invented a nanofluid-based ultrasensitive optical sensor that changes its colour on exposure to extremely low concentrations of toxic cations. The sensor is helpful in detecting minute traces of cations in industrial and environmental samples.Bachok et *al.,* (2011) investigated the effects of solid volume fraction and the type of the nanoparticles lying on the fluid flow and heat transfer characteristics of a nanofluid over a shrinking sheet[1].Chandrasekar*et al.,* (2015) applied a variation technique to the MHD, the radiative nanofluid flow over a non-isothermal stretching sheet through Brownian motion and thermophoresis effects by Gyarmati's principle[2].Gorla*et al.,* (2011) investigated the natural convection flow past horizontal plate in a porous medium[3].Hady*et al.*,(2012)studied the effects of thermal radiation on the viscous flow of a nanofluid and heat transfer over a non-linear sheet[4].Hamad*et al.,* (2011) illustrated the MHD convective flow of nanofluid through a linearly stretching layer[5].Kameswaran*et al.,* (2012) examined the Chemical reaction and Soret effect ofconvective nanofluid flow during a stretching or shrinking sheet in the presence of magnetic field and they concluded that decreases in wall heat transfer and mass transfer rates with increase in magnetic field[6].Khan *et al.,* (2010)studied the boundary layer flow of a nanofluid past a stretching sheet[7].Khan *et al.,* (2015) studied the forced convection analysis for generalized Burgers nanofluid flow over a stretching sheet[8].Lok*et al.,* (2010) study on stagnation point flow and heat transfer over a stretching or shrinking sheet has gained by lok[9].Maboode*t al.,* (2016) obtained an analytical result of an unsteady two-dimensional MHD nanofluid flow with heat and mass transfer over a heated surface [10].Mustafa *et al.,* (2015), analyze the analytical and numerical solutions for axisymmetric flow of nanofluid due to non-linearlystretchingsheet[11].

II. Mathematical Model

Consider cylindrical coordinate system (r,θ, z). Consider the laminar incompressible flow of Nanofluid over a circular sheet. The fluid resides in the half space $z \geq 0$ of the vertical axis. The sheet is stretched in its own plane with the power-law variation of velocity along the radial direction. The sheet is maintained at constant temperature T_w whereas nanoparticle mass flux at the wall is taken equal to zero. T_∞ and C_∞ denote the ambient values of temperature and nanoparticle volume fraction respectively. Under the natural boundary layer assumptions, the equations governing the conservation of mass, momentum, energy and nanoparticle volume fraction can be expressed as

Equation of Continuity

$$\frac{\partial u}{\partial r} + \frac{u}{r} + \frac{\partial w}{\partial z} = 0 \qquad (1)$$

Equation of Momentum

$$u\frac{\partial u}{\partial r} + w\frac{\partial u}{\partial z} = \nu_f \frac{\partial^2 u}{\partial z^2} \qquad (2)$$

Equation of Temperature

$$u\frac{\partial T}{\partial r} + w\frac{\partial T}{\partial z} = \alpha\frac{\partial^2 T}{\partial z^2} + \tau\left[D_B\frac{\partial C}{\partial z}\frac{\partial T}{\partial z} + \frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial z}\right)^2\right] + Q(T - T_\infty) \qquad (3)$$

Equation of Concentration

$$u\frac{\partial C}{\partial r} + w\frac{\partial C}{\partial z} = D_B\frac{\partial^2 C}{\partial z^2} + \frac{D_T}{T_\infty}\frac{\partial^2 T}{\partial z^2} + K(C - C_\infty) \qquad (4)$$

Where u and w are the velocity components along r-and z-directions respectively, $\hat{p}$ is the pressure, ν_f is the kinematic viscosity of the fluid, α is the thermal diffusivity, D_B is the Brownian diffusion coefficient, D_T is the thermophoretic diffusion coefficient, k is the thermal conductivity and τ is the ratio of effective heat capacity of the nanoparticle material to heat capacity of the fluid.the boundary conditions for the considered problem are ,

$$u = u_w(r) = ar^n, \quad T = T_w,$$

$$D_B\frac{\partial C}{\partial z} + \frac{D_T}{T_\infty}\frac{\partial T}{\partial z} = 0 \quad \text{at} \quad y = 0,$$

$$u \to 0, T \to T_\infty, C \to C_\infty \text{ as } y \to \infty \qquad (5)$$

In which $a > 0$ is the stretching constant and $n > 0$ is the power-law index. Here we use the similarity transformations

$$u = ar^n f'(\eta),$$

$$w = -ar^{\frac{(n-1)}{2}}\sqrt{\frac{\nu_f}{a}}\left(\frac{n+3}{2}f(\eta) + \frac{n-1}{2}\eta f'(\eta)\right),$$

$$\theta = \frac{T - T_\infty}{T_w - T_\infty}, \quad \phi = \frac{C - C_\infty}{C_\infty}, \quad \eta = \sqrt{\frac{a}{\nu_f}}r^{\frac{(n-1)}{2}}z.$$

(6) These similarity transformations satisfy the continuity equation (1). Obviously when n=3, yields the transformations.ThroughEqs. (2)-(5) we have,

$$f''' + \frac{n+3}{2}ff'' - nf'^2 = 0 \qquad (7)$$

$$\frac{1}{\Pr}\theta'' + \frac{n+3}{2}f\theta' + Nb\theta'\phi' + Nt\theta'^2 = 0 \qquad (8)$$

$$\phi'' + \frac{n+3}{2}Scf\phi' + \frac{Nt}{Nb}\theta'' = 0 \qquad (9)$$

$$\left.\begin{array}{l} f(0) = 0,\ f'(0) = 1, \theta(0) = 1, Nb\phi'(0) + \\ Nt\theta'(0) = 0, \\ f'(\infty) \to 0, \theta(\infty), \varphi(\infty) \to 0, \end{array}\right\} (10)$$

$$\left.\begin{aligned} &\Pr = \frac{\nu f}{\alpha}, Sc = \frac{\nu f}{D_B}, Nb = \frac{(\rho c)_p D_B C_\infty}{(\rho c)_f \nu f}, \\ &Nt = \frac{(\rho c)_p D_T (T_w - T_\infty)}{(\rho c)_f T_\infty \nu_f} \end{aligned}\right\} (11)$$

In the above equations Pr is Prandtl number, Sc is the Schmit number, Nb is the Brownian motion parameter and Nt is the thermophoresis parameter. Using variables (6), the local skin friction coefficient $C_f = \mu(\partial u / \partial z)_{z=0} / \rho f u_w^2$ and the localNusseltnumber $Nu = -r(\partial T / \partial z)_{z=0} / (T_w - T_\infty)$ can be put into the following forms,

$$\mathrm{Re}_r^{\frac{1}{2}} C_f = f''(0), \quad \mathrm{Re}_r^{\frac{-1}{2}} Nu = -\theta'(0) \quad (12)$$

III. Numerical Result

In this paper,we analyze the numerical solutions for laminar incompressible flow of nanofluid over a circular sheet with heat and mass transfer. The governing boundary layer equations are transformed to ordinary differential equations by using similarity transformation. Then they are solved by Runge kutta sixth order method. The obtained numerical results are illustrated graphically for different values done by using mathematica computer language. From the process of numerical computation, the fluid's Prandtl number, schmit number are analyzed with comparsion of analytical result in Mustafa(2015).

IV. Result and Discussion

From this research, we have found various changes in many parameters by increasing the values of Prandtl number, Power law index, Thermophoresis, Schmidt number and Brownian motion parameter. The results are displayed graphically for different parameters.In figure 1 when the Prandtl number increases then the temperature profile decreases. From figure 2 power law index is increase then the temperature profile decrease. From figure 3 Prandtl number increases then the temperature decrease. From figure 4 when the Schmidt number increase then the temperature profile increase. From figure 5 when the

Where,

$\mathrm{Re}_r = u_w r / \nu f$ is the local Reynolds number. The reduced Sherwood number, which is the dimensionless mass flux, is now identically zero.

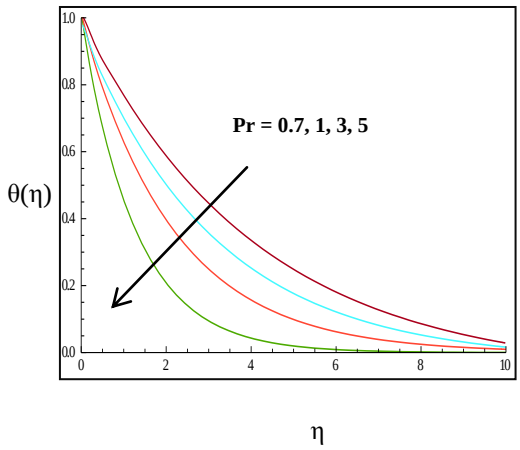

Figure.1.Temperature profile for Different values of Pr

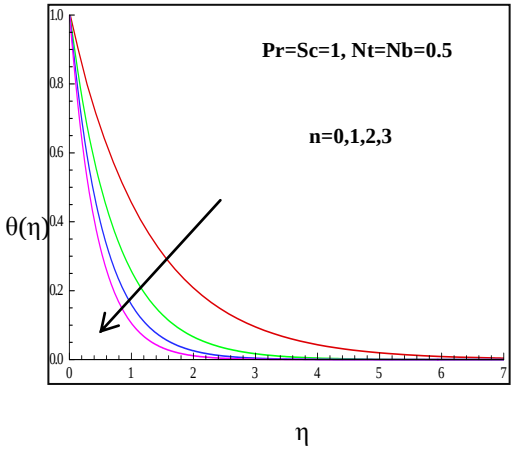

Figure.2.Temperature profile for different values of n

thermophoresis increase then the temperature profile increase. From figure 6 when the thermophoresis increase then the volume fraction increase. From the figure 7 when the Brownian motion increase increase then the volume fraction decrease.

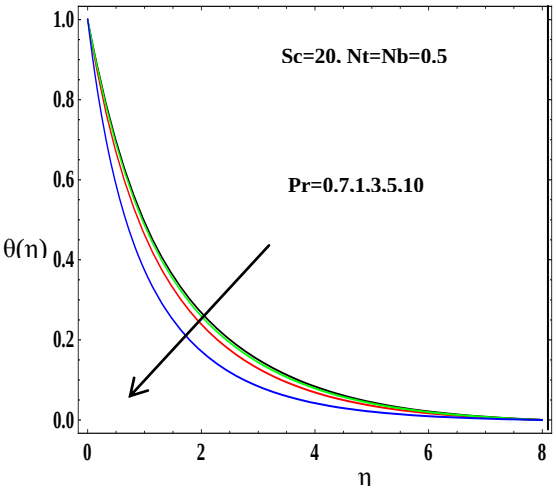

Figure.3. Effect of Pr on θ

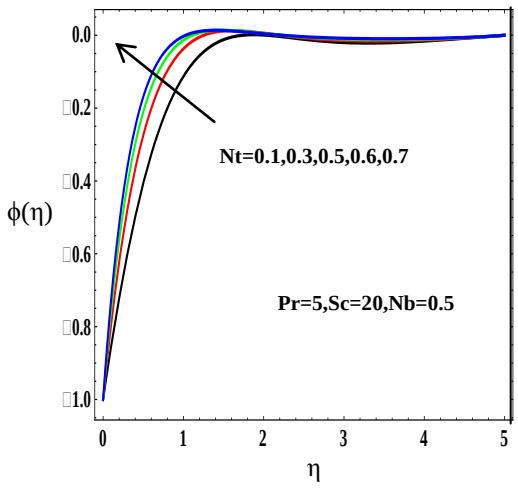

Figure 6.Effect of Nt on ϕ

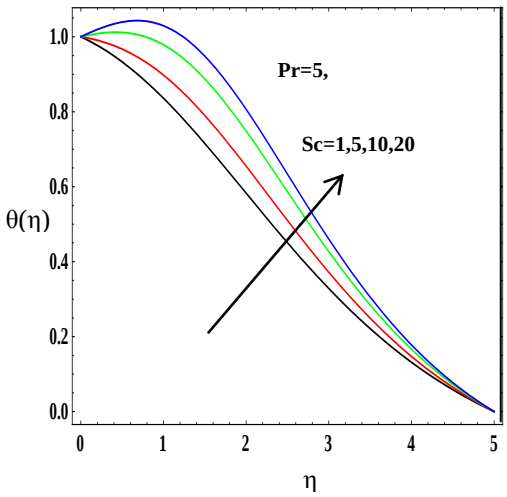

Figure.4. Effect of Sc on θ

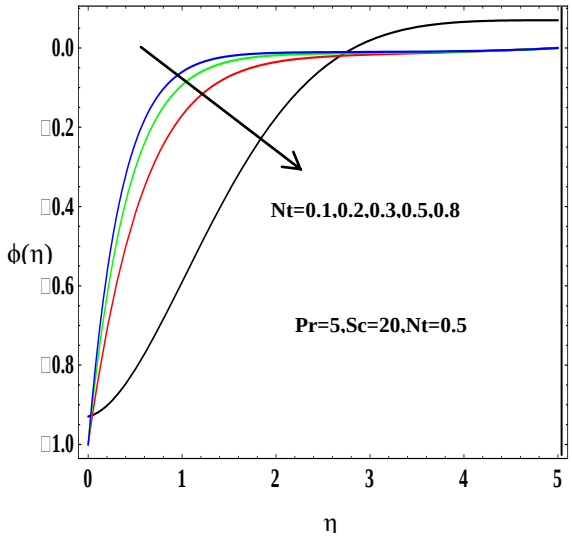

Figure 7.Effect of Nb on ϕ

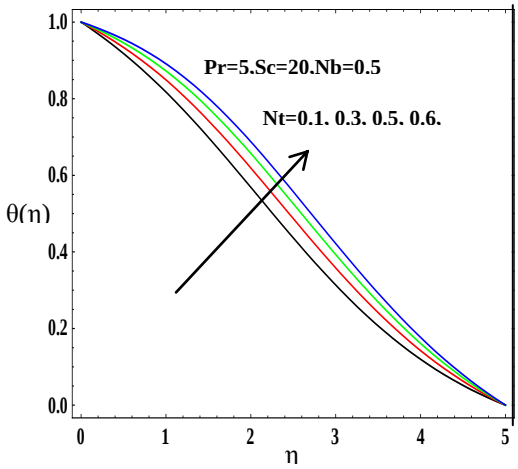

Figure.5. Effect of Nt on θ

V. Conclusion:

This study is an investigation of flow, heat and mass transfer behavior of laminar incompressible flow over a circular sheet with heat and mass transfer. The results obtained from this study are given below,

- Prandtl number increase then the temperature profile decrease.
- Increasing the value of n it reduces the thickness of thermal and nano-particle volume fraction boundary layer.
- Thermal boundary layer grows with an increment in thermophoresis (Nt).
- An increase in Nt shifts the nano-particles away from the sheet and forms a particle free layer in the vicinity of the sheet.

References

[1]. Bachok.N, Ishak.A and Pop.I (2011), "Stagnation Point Flow over a Stretching/Shrinking Sheet in a Nanofluid",Nanoscale.Res.Lett, 6,pp.623-*632.*

[2]. Chandrasekar.M and Kasiviswanathan.M.S (2015), "Analysis of Heat and Mass Transfer on MHD Flow of a Nanofluid Past a Stretching Sheet",*J.Procedia Engineering, 127, pp.493-500.*

[3]. Gorla.R.S.R and Chamkha.A (2011), "Natural Convective Boundary Layer Flow Over a Horizontal Plate Embedded in a Porous Medium Saturated with a Nanofluid",*J.Mod.Phy, 2, pp.62-71*

[4]. Hady.F.M, Ibrahim.F.S, Abdel-Gaied.S.M and Eid.M.R (2012), "Radiation Effect on Viscous Flow of a Nanofluid and Heat Transfer over a nonlinearly Stretching Sheet", *Nanoscale. Res.Lett, 7, pp.229-236.*

[5]. Hamad.M.A.A (2011), "Analytical Solution of Natural Convection Flow of a Nanofluid over a Linearly Stretching Sheet in the Presence of Magnetic Field",*Int.comm.in Heat and mass Trans, 38(4), pp.487-492.*

[6]. Kameswaran.P.K, Narayana.M, Sibanda.P and Murthy.P.V.S.N (2012), "Hydromagnetic Nanofluid Flow Due to a Stretching or Shrinking Sheet with Viscous Dissipation and Chemical Reaction Effects",*Int.J.Heat and Mass Transfer, 55(25), pp.7587-7595.*

[7]. Khan.M and Khan.W.A (2015), "Forced Convection Analysis for Generalized Burgers Nanofluid Flow over a Stretching Sheet", *AIP Advances, 5, pp.107-138.*

[8]. Khan.W.A and Pop.I (2010), "Boundary Layer Flow of a Nanofluid Past a Stretching sheet", *Int.J.Heat and Mass Transf, 53, pp.2477-2483.*

[9]. Lok.Y.Y, Merkin.J.H and Pop.I (2012), "Mixed Convection Flow near the axisymmetric Stagnation Point on a Stretching or Shrinking Sheet", *Int.J.Therm.Sci.,59, pp.186-194.*

[10]. Mabood.F and Khan.W.A (2016), "Analytical Study for Unsteady Nanofluid MHD Flow Impinging on Heated Stretching Sheet", *Journal of Molecular Liquids, 219, pp.216-223.*

[11]. Mustafa.M, Junaid Ahmad Khan (2015),"Analyticalandnumericalsolutionsforaxisymmetric flowofnanofluid due tonon-linearlystretchingsheet", *International Journal of Non-Linear Mechanics,http://dx.doi.org/10.1016/j.ijnonlinmec.2015.01.005i.*
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