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Brownian motion and thermophoresis in SWCNT due to bidirectional rotating stretching surface

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ABSTRACT: *Rotating Maxwell nanofluid over a bidirectional stretching sheet with single wall carbon nanotube (SWCNT) is considered. Brownian motion, double stratification and thermophoresis are work out in heat and mass transfer. Basic equations of motion are converted into ordinary differential equation by suitable transformations. Then the corresponding equations are solved numerically and graphically. Numerical results are compared with previously published article and it made good agreement with results.*

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I. INTRODUCTION

The study of systems involving energy in the form of heat and work is known as thermodynamics. Brownian motion is the random movement of a particle caused by collisions with nearby gaseous molecules. Thermophoresis is the transport force that occurs when a temperature gradient exists. Dumitru Baleanu[6] studied and examined the crossbred engine oil based CNTs for heat and mass transfer over rotating disk nanofluid and under magnetic field effects. Comparison of SWCNT and MWCNT is taken into account of moving rotating disks in nanofluids with magnetic field. Manjunatha[12] shows reasonable solution with nanomaterial and boundary layer by using shooting technique. In the direction parallel to the plate, three dimensional rotating flow with Lorentz force in Maxwell nanofluid is investigated along Riga plate and bio convection with micro-organisms is also induced. Finite element method is used to solve this problem by Bagh Ali[4]. Influence of heat source sink is studied by Alreshidi[2] in porous rotating disk and magnetohydrodynamic (MHD) nanofluid flow with slip conditions. Effects of joule dissipation is also considered and applied numerical and analytical techniques to solve this problem. Hammad [1] investigated micropolar Riga plate with viscous nanofluid flow by mixed convection, thermophoresis and Brownian motion. This model is resolved through numerically by Keller box technique.

Bagh Ali[3] considered boundary value problem with micro-organisms through nanoparticles over a rotating surface. Cattaneo-Christov heat flux model is also considered by temperature profile. Lorentz and Coriolis force, and activation energy are induce the heat and mass transfer. Nanomaterial fluid over an angled rotating disc with thin film moment is considered by Zeeshan[17]. This model is solved through Runge-Kutta fourth order technique and HAM solution by numerically. Hayat[8] introduced third grade nanofluid across rotating stretching disk with chemical reaction and heat source. HAM method is used to analyze good solutions for various parameters. Impact of Coriolis force, activation energy, electromagnetic field and chemical reaction over a Riga plate in rotating nanofluids. The non-Fourier heat flux model is considered by Bagh Ali[5] and solved through finite element method.

Analysis of thin liquid flow is examined with non-linear system of Maxwell nanofluid by Uddin[10]. Thermal radiation and magnetic field along rotating disk is solved through Adams method. Arshad[13] considered Brownian motion and thermophoresis profile via an exponential surface with chemical reaction and magnetic strength. Comparative study of water and ethanol over an industrial application. El-zahar[7] modeled viscous dissipation and Brownian motion in Jeffery nanofluid over a moving surface with thermophoresis. Impact of thermal radiation and magnetic field with combined effect of heat and mass transfer are considered by Hassanan[9]. SWCNT and MWCNT are subjected to Newtonian heating condition for this study.

Reddy[16] is explored non-linear stretching/shrinking sheet in MHD flow with viscous dissipation and heat generation over CNT nanofluid. Saleem[14] demonstrated nanomaterial on SWCNT in three dimensional rotating stretched surface with thermal radiation, thermophoresis, Brownian motion and thermal conductivity. Maxwell nanofluid is introduced with many effect of heat and mass transfer but especially dufour and soret effect is used in this problem by Prasannakumara[15].

After studied through the above articles, the many researchers modeled most of the effects of velocity, heat and mass transfer. But in this paper, bidirectional stretching surface is considered with thermophoresis, Brownian motion and double stratification. This problem is solved through numerically and compared the results with previously published articles.

II. MATHEMATICAL DEMONSTRATION

Consider the model with steady, Maxwell condition, incompressible rotating flow past a stretching surface. The fluid motion is illustrated in three dimensional which occurs in z-direction with constant angular velocity ω due to Coriolis force. The velocity of the fluid flows u_1, v_1 and w_1 in the x, y and z-directions respectively. The velocities at the wall u = a_1x(x-direction) and v = a_2y(y-direction), where a_1 and a_2 are positive real numbers). The equation of energy is updated to simulate thermal and solute impacts with double stratification. Brownian motion and thermophoresis are induced in heat and mass transfer. The surface and ambient temperatures and concentrations are T_w and T_∞, and C_w and C_∞ respectively. The governing equations of the flow and heat transfer in Maxwell condition are as follows:

$$\frac{\partial u_1}{\partial x}+\frac{\partial v_1}{\partial y}+\frac{\partial w_1}{\partial z}=0 \tag{1}$$

$$u_1\frac{\partial u_1}{\partial x}+v_1\frac{\partial u_1}{\partial y}+w_1\frac{\partial u_1}{\partial z}-2\omega v_1=\frac{\mu_{nf}}{\rho_{nf}}\frac{\partial^2 u_1}{\partial z^2}-\lambda_1\left[u_1^2\frac{\partial^2 u_1}{\partial x^2}+v_1^2\frac{\partial^2 u_1}{\partial y^2}+w_1^2\frac{\partial^2 u_1}{\partial z^2}+2u_1v_1\frac{\partial^2 u_1}{\partial x\partial y}\right.$$
$$\left.+2v_1w_1\frac{\partial^2 u_1}{\partial y\partial z}+2u_1w_1\frac{\partial^2 u_1}{\partial x\partial z}-2\omega\left(u_1\frac{\partial v_1}{\partial x}+v_1\frac{\partial v_1}{\partial y}+w_1\frac{\partial v_1}{\partial z}\right)+2\omega\left(v_1\frac{\partial u_1}{\partial x}-u_1\frac{\partial u_1}{\partial y}\right)\right] \tag{2}$$

$$u_1\frac{\partial v_1}{\partial x}+v_1\frac{\partial v_1}{\partial y}+w_1\frac{\partial v_1}{\partial z}+2\omega u_1=\frac{\mu_{nf}}{\rho_{nf}}\frac{\partial^2 v_1}{\partial z^2}-\lambda_1\left[u_1^2\frac{\partial^2 v_1}{\partial x^2}+v_1^2\frac{\partial^2 v_1}{\partial y^2}+w_1^2\frac{\partial^2 v_1}{\partial z^2}+2u_1v_1\frac{\partial^2 v_1}{\partial x\partial y}\right.$$
$$\left.+2v_1w_1\frac{\partial^2 v_1}{\partial y\partial z}+2u_1w_1\frac{\partial^2 v_1}{\partial x\partial z}-2\omega\left(u_1\frac{\partial u_1}{\partial x}+v_1\frac{\partial u_1}{\partial y}+w_1\frac{\partial u_1}{\partial z}\right)+2\omega\left(v_1\frac{\partial v_1}{\partial x}-u_1\frac{\partial v_1}{\partial y}\right)\right] \tag{3}$$

$$u_1\frac{\partial T}{\partial x}+v_1\frac{\partial T}{\partial y}+w_1\frac{\partial T}{\partial z}=\frac{k_{nf}}{(\rho c_p)_{nf}}\frac{\partial^2 T}{\partial z^2}+\frac{(\rho c_p)_{np}}{(\rho c_p)_{nf}}\left\{D_B\frac{\partial T}{\partial z}\frac{\partial C}{\partial z}+\frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial z}\right)^2\right\} \tag{4}$$

$$u_1\frac{\partial C}{\partial x}+v_1\frac{\partial C}{\partial y}+w_1\frac{\partial C}{\partial z}=D_B\frac{\partial^2 C}{\partial z^2}+\frac{D_T}{T_\infty}\frac{\partial^2 T}{\partial z^2} \tag{5}$$

With this equations thermophysical properties for Maxwell nanofluid and associated boundary conditions,

$$\text{At } z=0, u_1=a_1x, v_1=a_2y, w_1=0, T_w=T=d_1x+T_0,\ C_w=C=d_2x+C_0$$
$$\text{As } z\to\infty, u_1\to 0, v_1\to 0, T\to T_\infty=T_0+e_1x, C\to C_\infty=C_0+e_2x \tag{6}$$

The dimensionless transformation of the mathematical model are:

$$u_1=a_1xf'(\zeta),\ v_1=a_1yg'(\zeta),\ w_1=-\sqrt{a_1\upsilon}[f(\zeta)+g(\zeta)],$$
$$\zeta=\sqrt{\frac{a_1}{\upsilon}}z,\ \theta(\zeta)=\frac{T-T_\infty}{T_w-T_0},\ \phi(\zeta)=\frac{C-C_\infty}{C_w-C_0} \tag{7}$$

By this transformation, Eqn (1) satisfies. While Eqs (2) to (5) are:

$$f'''\left(\frac{\Pi_1}{\Pi_2}-\beta(f+g)^2\right)-f'^2+2\lambda E_1g'+2\beta f'f''(f+g)+(f+g)f''+2\lambda\beta E_1\left(g'^2-(f+g)g''-f'g'\right)=0 \tag{8}$$

$$g'''\left(\frac{\Pi_1}{\Pi_2}-\beta(f+g)^2\right)+g''(f+g)-g'^2+2\beta(f+g)g'g''-2\lambda E_2f'+2\lambda\beta E_2\left((f+g)f''-f'^2+f'g'\right)=0 \tag{9}$$

$$\theta''+\frac{Pr\Pi_3}{\Pi_5}\left[(f+g)\theta'-f'(S_1+\theta)\right]+\frac{Pr}{\Pi_5}(Nb\,\theta'\Phi'+Nt\,\theta'^2=0 \tag{10}$$

$$\Phi''+Sc\left[(f+g)\Phi'-f'(S_2+\Phi)\right]+\frac{Nt}{Nb}\theta''=0 \tag{11}$$

Subjected to the boundary conditions are:

$$\text{At } \zeta = 0, \quad f' = 1, \quad g' = S, \quad \theta = 1 - S_1, \quad \Phi = 1 - S_2$$

$$\text{As } \zeta \to \infty, \quad f' = g' = 0, \quad \theta = 0, \quad \Phi = 0 \tag{12}$$

Where Πi′s, i = 1, 2…5 in Eqs (8) - (11) shows the Thermophysical properties for the Maxwell nanofluid,

$$\Pi_1 = (1-\phi)^{2.5}, \quad \Pi_2 = \left(1 - \phi + \phi \frac{\rho_{np}}{\rho_{bf}}\right), \quad \Pi_3 = \left(1 - \phi + \phi \frac{(\rho c_p)_{np}}{(\rho c_p)_{bf}}\right),$$

$$\Pi_4 = \left[1 + \frac{3\left(\frac{\sigma_{np}}{\sigma_{bf}} - 1\right)\phi}{\left(\frac{\sigma_{np}}{\sigma_{bf}} + 2\right) - \left(\frac{\sigma_{np}}{\sigma_{bf}} - 1\right)\phi}\right], \quad \Pi_5 = \left[\frac{(k_{np} + 2k_{bf}) - 2\phi(k_{bf} - k_{np})}{(k_{np} + 2k_{bf}) + \phi(k_{bf} - k_{np})}\right]$$

The parameters are defined here by $\beta = \lambda_1 a_1$ is the Deborah relaxation number, $\lambda = \omega / a_1$ rotation parameter, $S = a_2/a_1$ stretching ratio, $Sc = \upsilon_{bf}/D$ Schmidt number, Brownian motion $Nb = (\rho cp)_{np} D_B (C_w - C_0)/ \upsilon_{bf}(\rho cp)_{bf}$, Thermophoresis $Nt = (\rho cp)_{np} D_T (T_w - T_0)/ \upsilon_{bf} T_\infty (\rho cp)_{bf}$, $Pr = \upsilon_{bf}(\rho cp)_{bf} / k_{bf}$ Prandtl number, $S_2 = e_2/d_2$ concentration stratification and $S_1 = e_1/d_1$ thermal stratification.

By setting down the PDE Equations (8) through (11) as an initial value problem with boundary conditions, we want to: f = H(1), f' = H(2), f'' = H(3), g = H(4), g' = H(5), g'' = H(6), θ = H(7), θ' = H(8), Φ' = H(9), Φ''= H(10) and then, we obtain the first-order equation system then it solve through bvp4c Matlab solver.

III. RESULTS AND DISCUSSION

Maxwell nanofluid with rotating stretching sheet over a SWCNT are considered and Brownian motion and thermophoresis also take part in this model to find heat and mass transfer rate. While considering rotating flow, the fluid flow strength is reduced and surface start to reduce fluid velocity also. Thus, rising of rotation strength becomes low velocity which shows in Figure 1 and 2. Effects of Maxwell parameter in velocity field and momentum layer in Figure 3 and 4. In a nanofluid with SWCNT, the Maxwell condition is applied to fluid and started to increase the level of condition, then velocity field reduces its nature with thinner boundary. Finally velocity reduces to negative direction in y stream of stretching surface. By increasing volume fraction, velocity in x-direction rises and in y-stream it starts to rise but after some turn over point (critical point), it starts to reduce velocity and boundary becomes thinner.

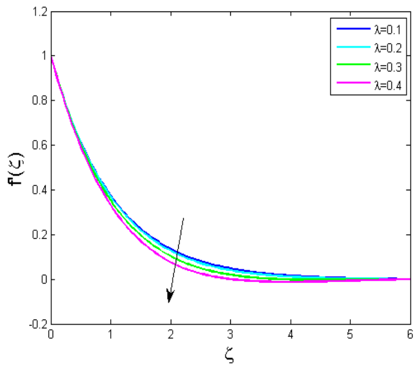

Fig 1. Velocity f ‘(ζ) on λ

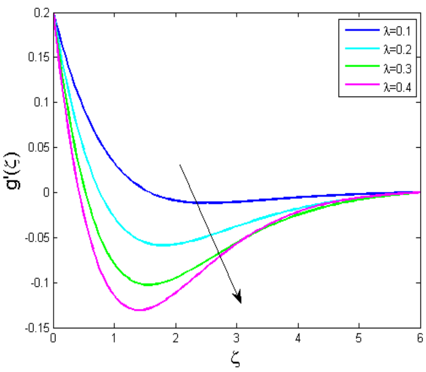

Fig 2. Velocity g ‘(ζ) on λ

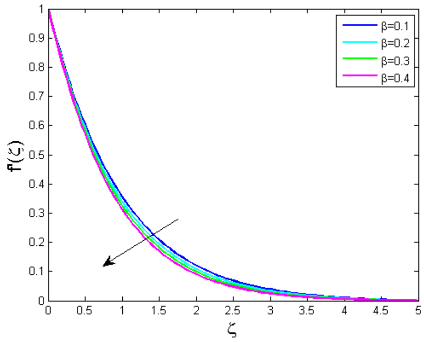

Fig 3. Velocity f ‘(ζ) on β

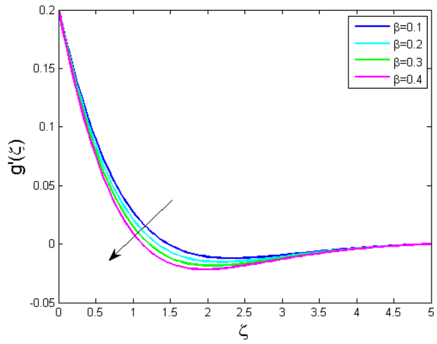

Fig 4. Velocity g ‘(ζ) on β

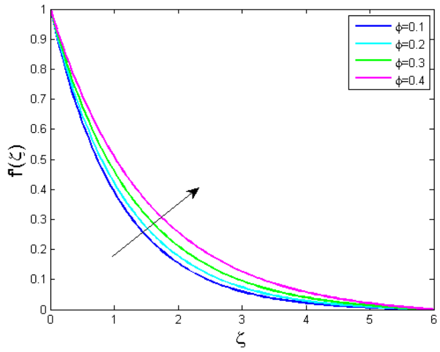

Fig 5. Velocity f ‘(ζ) on ϕ

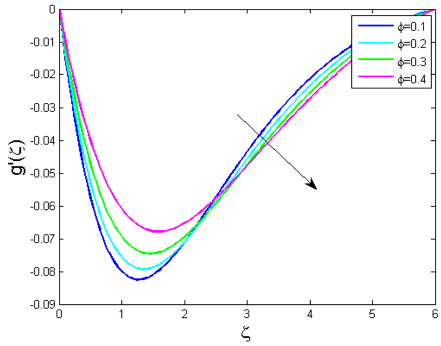

Fig 6. Velocity f ‘(ζ) on ϕ

On the whole, in y-direction velocity occurs in negative direction after a while it starts it rise to converge in positive direction. That is, in Figure 5 and 6 shows that whatever the condition, velocity reduces and also in rising of volume fraction.

Impact of thermophoresis in heat and mass transfer illustrates in Figure 7 and 8. If increasing the thermophoresis (Nt), the temperature and concentration also increases and it converge to zero. Because rising of thermophoresis, the nanoparticle start to stir up then fluid has more viscosity. So heat and mass transfer also rises. Figure 9 and 10 shows the effects of Brownian motion, temperature and concentration. While Brownian motion goes high then temperature also increases but concentration in resistance of the fluid stream which shows that liquid becomes more viscosity. Figure 11 displays temperature in the effects of Prandtl number.

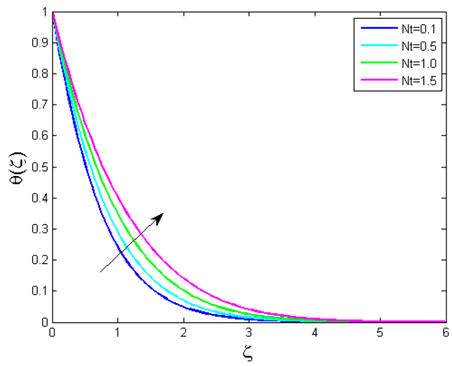

Fig 7. Temperature θ (ζ) on Nt

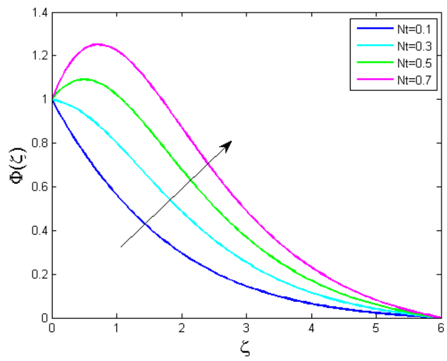

Fig 8. Concentration Φ (ζ) on Nt

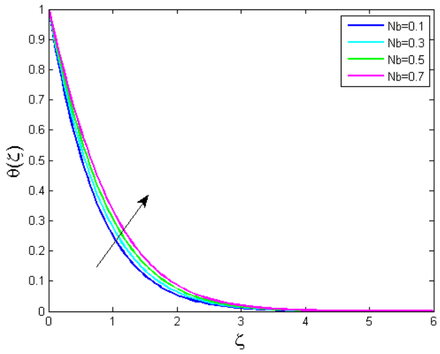

Fig 9. Temperature θ (ζ) on Nb

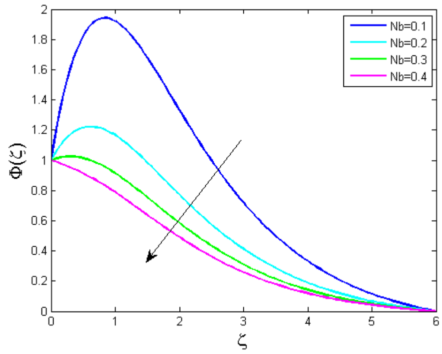

Fig 10. Concentration Φ (ζ) on Nb

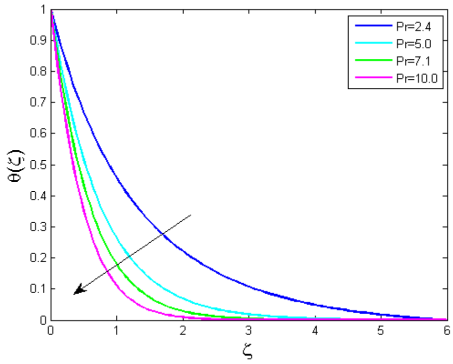

Fig 11. Temperature θ (ζ) on Pr

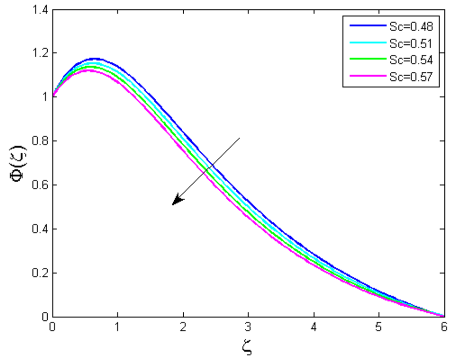

Fig 12. Concentration Φ (ζ) on Sc

Larger Prandtl number gives lower temperature. This shows that nanofluid with SWCNT made surface to cool. Schmidt number effects with concentration shows in Figure 12. Higher Schmidt number forms smaller magnitude that is, there is low resistance in mass transfer. By rising Schmidt number, the viscosity becomes stronger then mass transfer capacity goes to reduce in low magnitude.

Table 1. Physical properties of SWCNT with base fluid.

Physical Properties	Density ρ (kg / m3)	Specific heat C p (J / kg K)	Thermal conductivity k (W / m K)
Water	997	4179	0.613
SWCNT	2600	425	6600

Table 2. Comparison of f '' (0).

β	Khan et al. [11]	Current result
0.0	1.00000	1.000001
0.2	1.05189	1.051890
0.4	1.10190	1.101903
0.6	1.15014	1.150137

Table 3. Numerical results over –θ' (0) and –Φ' (0)

Nt	Nb	Sc	-θ' (0)	-Φ' (0)
0.1	0.1	0.1	0.119387	0.341974
0.3			0.119131	0.293928
0.5			0.118876	0.246564
	0.5		0.118516	0.361529
	1.0		0.117435	0.363970
	1.5		0.116364	0.364784
		0.5	0.119330	0.844527
		1.0	0.119316	1.215468
		1.5	0.119309	1.498961

Table 1. displays properties of SWCNT nanofluid. Table 2. displays the comparison of previous article with present result. The Maxwell parameter increases the f ''(0) also increases which got good agreement with previous paper. Table 3. shows effects of Brownian motion, thermophoresis and Schmidt number with –θ'(0) and –Φ'(0). Brownian motion increases then –θ'(0) and –Φ'(0) both reduces because of SWCNT with nanofluid work as cooling substance. High level of thermophoresis gives low temperature but high concentration with the help of viscosity transformation occurs in fluid substance. Increase of Schmidt number with more viscous force, the fluid goes low temperature but there is high concentration.

IV. CONCLUSION

Velocity reduces in high rotation strength, Maxwell parameter and volume fraction on both x and y direction, but in high volume fraction increases velocity in x-direction alone. All the momentum parameter rises velocity shows in resistance of fluid stream which decreases almost. The temperature reduces only when the Prandtl number increases. When the thermophoresis increases, the concentration also increases and other than that it decreases.

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