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Influences of bio-convection and activation energy on Maxwell flow of Nano-fluid in the existence of motile microorganisms over a cylinder

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Abstract

In this article, A three-dimensional Maxwell Nano fluid with the significance of activation energy, mixed convection, motile microorganisms and boundary condition over a rotating circular cylinder is deliberated. The flow is caused by rotating the cylinder. Brownian gesture and thermo-phoresis effects remain shown in the nano-fluid model. By using the shooting method, the given differential partial equations (PDES) exist willingly converted into differential ordinary nonlinear equations, by the support of appropriate transformation variables.

Obtained equations are verified numerically through some proper and well define bvp4c techniques and computational software MATLAB with their physical effects. The results of various parameters on temperature, velocities volumetric, concentration and motile microorganism's distribution are shown graphically. The Maxwell Nano liquid for a fixed consistent wall temperature (CWT) transfers more heat energy as compared to prescribed surface temperature (PST).

Keywords: Maxwell fluid, bio convection, Bvp4c, Shooting method

Introduction

In earlier times, the behavior of non-Newtonian fluid flow fascinated engineers and researchers in engineering as well as in industrial sciences. Non-Newtonian fluids are comprehensively used in various engineering and manufacturing processes. Polymer processes, biomechanics, enhanced oil recovery, and food production are included in these processes. That is why it is impossible to describe these rheological features of fluids in a single constitutive equation. Therefore, a number of equations are described to make explicit the properties of these non-Newtonian fluid models. Non-Newtonian fluids have a type known as tangent hyperbolic fluids. This model enables us to predict the shear thinning phenomenon. Tangent hyperbolic fluid measures the resistance to fluid flow when flow slows down with an increasing shear stress rate. Additionally, in laboratory experiments, the tangent hyperbolic fluid model predicts shear thinning phenomena accurately. The tangent hyperbolic fluid is a class of fluid that measures the fluid's resistance at a dominant rate of shear stress when fluid flow decreases.

The term "Nano fluid" was suggested [1] and for the first time, the aspects of thermo phonetically and Brownian motion limitation are considered. This distinguished theory emphasizes that, in the presence of diverse fluid models, researchers show fascinating flow properties for different Nano fluids. Micro fluids have shown higher tendency as compared to foundation fluids such as propylene glycol water and gasoline. A range of electronic implementations include drug company storage, biotechnology (nondrug delivery, cancer therapy, regenerative medicine, Nano surgery, sensing imaging etc.). Buongiorno [2] studied convective Nano fluid transportation inspections. The effects of Cu-O quantum dots on the thermal transfer computing behavior of PCM during the thermal decomposition process have been examined by [3] taking into account the consideration of its radiate dedication sentence.

In 2016 [4] presented a stretchable sheet with a non-Newtonian fluid model. They accounted for the flow regime impacts of mixed convection and chemical reactions. Now, a number of technological and scientific researchers have already shown a growing interest in non-Newton-ian substances, as these technologies play a key role in the production of industrial companies. [5] Directed on the effect of monitorial field and heat waves on Nano fluid's open Convecção movement over a linear stretch layer.

(MHD) is to elaborate the dynamics of electrical conductive fluid's (magneto fluid dynamics or hydro magnetic). Because of its certain applications in making, electronics, & metallurgical procedure, the magneto hydrodynamic (MHD) movement of an electrically conductive fluid is the flest common region of study. Several uses of this are industrial use of plasma, modifying process of the metal solid-faction cycle, cooling of nuclear reactors, optimization of processes for crystal production, regulation of melting flow in the propagation of semi-conductors in bulk crystals, magneto hydrodynamic (MHD) power generators, etc.

The basic principle behind MHD is that in a moving conductive fluid, magnetic fields may cause currents, which in effect induce forces on the fluid and shift the magnetic field itself Fig.1. magneto hydrodynamic (MHD) plays a vital role in metallurgical science, aerodynamics, field dynamics engineering, composite engineering and heat exchange etc. Magneto hydrodynamic (MHD) is applicable in biomedical engineering for magnetic ambition in cancer diseases, sterilized equipment, asthma treatment, gastric medications, targeted drugs, and elimination of tumors with hyperthermia. Several scientists have studied various personality issues related to the characteristics of magneto hydrodynamic (MHD) Nano fluid flow and the boundary layer. MHD heat and mass transformation by power degradation, pressure function on a flexible expansion area.

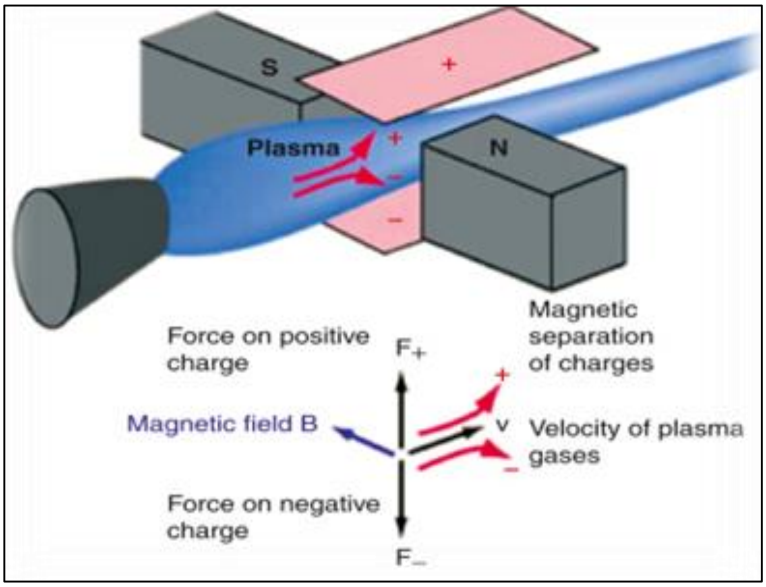

Fig 1: MHD effect on Maxwell Fluid

[6] Analyzed the mixed convection effect of the Max-well nano-fluid 3D flow induct by a vertically spinning and elongating container. In a motley convective occurrence, the toughness strength in the liquid shows a significant part in the transportation of heat energy.

Bio-convection has been induced by microscopic convection created by the gradient of density produced by the combine motion of self-propelled motile micro-organisms within the liquid. bio convection have many usess in biological phenomenon and biotechnologies. Despite the large number of publications regarding bio convection in gyro tactic microorganism suspensions, relatively few of them discuss this form of bio convection in saturated porous fluid medium. This phenomenon is significant because it can occur in nature and can also have various applications. [7] discovered a basic concept of bio convection. [8] dealt with the mathematical approximation of the bio convection issue of the silvery needle nanotube. [9] identified the results of the nervier slide boundary of Nano fluid using gyrostatic microorganisms. [10] investigated the effect of relative humidity-dependent conductivity and density on saturated soluble bio convection nano-particles. [11] used mathematically the results of organisms in uniform third-degree water over the stretching surface. [12-13] Described the effects of bio convection at the dispersed Nano-fluid of energy and volume exchange. This plays a key role in the modern world's processes and has broad implementations that attract scientists. Numerous studies are required to illustrate the characteristics and Nano fluid gripping for commercial applications, including nuclear fission, food, telecommunication, physiology, transport, etc. For geotactic microorganisms, established the first theory of gravitate bio convection. This theory is based on the Navies Stokes equation with the Bossiness approximation and the equation for the conservation of motile microorganism concentration.

[14] On an increasingly extending ground, we investigated the non-Newtonian Maxwell MHD liquid with non-materials. Considerable research has been conducted on the difficulties of linear and nonlinear extending surface. The flow owing to the increasingly stretched surface was also explored using Pioneer's methodology. [15] The heat and mass transmission of the higher converted Maxwell non-material travelling over a linear permeable stretching surface at the stagnation - point flow region was investigated (Cattaneo–Christov model). Convocational Fourier and Fick's laws were concerned with the occurrences of heat and mass. [16] The angular velocity of the Maxwell Nano - fluids had dropped significantly by a greater magnitude than the made by mixing bio convection vector, according to the inspection. The lowered properties of Available for multiple number and Bio convective heat Lewis number were shown to be the concentration region of Maxwell Nano fluid by micro - organisms. [17] The rise in concentration and temperature distributed with increasing instability, curvature, and Maxwell parameters in several equations such as equation of inertia, equation of energy, and calculation of density were investigated. The superior kind of non-Newtonian liquid where both viscoelastic pressures were identified was the Maxwell fluid.

Material and Formula's

Think through the bio-convection stream of Maxwell Nano-fluid holding motile micro-organ past a elongating container of radiusR_1. The actions of thermo-phoresis diffusion and Brownian motion are considered for nano-particles. The combined Buongiorno model and Kuznets model is used to established the current precise model.

The field lines are acted in the way of $r-axis$. Velocity components (u, v, w) are taken in the (z, φ, r).

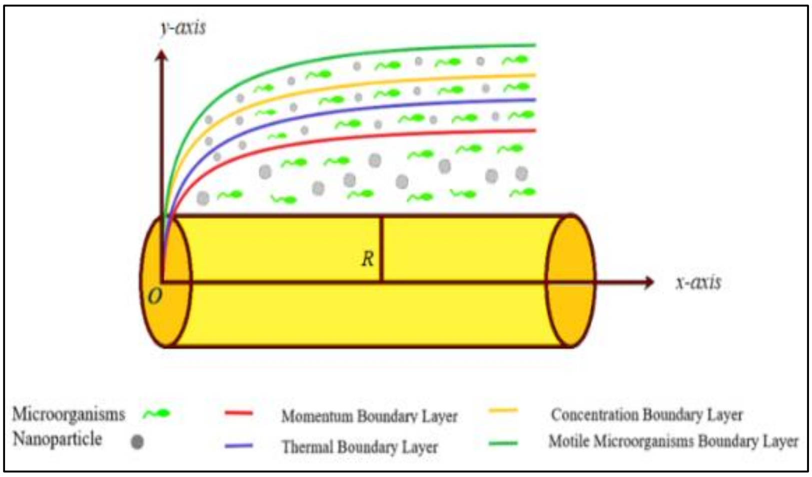

Fig 2: Maxwell Fluid

The governing equations of model are:

$$\frac{\partial u}{\partial z}+\frac{w}{r}+\frac{\partial w}{\partial r}=0, \tag{1}$$

$$u\frac{\partial u}{\partial z}+w\frac{\partial u}{\partial r}+\lambda_1\left(u^2\frac{\partial^2 u}{\partial z^2}+2uw\frac{\partial^2 u}{\partial r\partial z}+w^2\frac{\partial^2 u}{\partial r^2}\right)=\nu\left(\frac{\partial^2 u}{\partial r^2}+\frac{1}{r}\frac{\partial u}{\partial r}\right)-\frac{\sigma\beta_0^2}{\rho}\left(u+\lambda_1 w\frac{\partial u}{\partial r}\right) \tag{2}$$

$$u\frac{\partial v}{\partial z}+w\frac{\partial v}{\partial r}+\frac{wv}{r}+\lambda_1(u^2\frac{\partial^2 v}{\partial z^2}+2uw\frac{\partial^2 v}{\partial r\partial z}+w^2\frac{\partial^2 v}{\partial r^2}+\frac{2wv}{r}\frac{\partial w}{\partial r}+\frac{2uv}{r}\frac{\partial w}{\partial z}-\frac{2w^2v}{r^2})=\nu(\frac{\partial^2 v}{\partial r^2}-\frac{v}{r^2}+\frac{1}{r}\frac{\partial v}{\partial r})-\frac{\sigma B_0^2}{\rho}(\mathrm{v}+\lambda_1 w\frac{\partial v}{\partial r}-\lambda_1\frac{wv}{r}), \tag{3}$$

$$u\frac{\partial T}{\partial z}+w\frac{\partial T}{\partial r}=\alpha_1(\frac{\partial^2 T}{\partial r^2}+\frac{1}{r}\frac{\partial T}{\partial r})+\tau(D_B\frac{\partial C}{\partial r}\frac{\partial T}{\partial r}+\frac{D_T}{T_\infty}(\frac{\partial T}{\partial r})^2)-\frac{1}{\rho c_p}\frac{1}{r}\frac{\partial}{\partial r}(rq_r)+\frac{\alpha B_0^2}{\rho c_p}(u^2+v^2)+\frac{Q_0}{\rho c_p}(T-T_\infty), \tag{4}$$

$$u\frac{\partial C}{\partial z}+w\frac{\partial C}{\partial r}=D_B\left(\frac{\partial^2 C}{\partial r^2}+\frac{1}{r}\frac{\partial C}{\partial r}\right)+\frac{D_T}{T_\infty}\left(\frac{\partial^2 T}{\partial r^2}+\frac{1}{r}\frac{\partial T}{\partial r}\right)+K_1 r^2(C-C_\infty)\left(\frac{T}{T_\infty}\right)^2\exp\left(\frac{-E_a}{kT}\right), \tag{5}$$

$$u\frac{\partial N}{\partial z}+w\frac{\partial N}{\partial r}+\left[\frac{\partial}{\partial r}\left(N\frac{\partial C}{\partial r}\right)\right]\frac{bW_c}{(C_w-C_\infty)}=D_m\frac{\partial}{\partial r}\left(\frac{\partial N}{\partial r}\right). \tag{6}$$

With boundary conditions

$$u_s=2az, v_s=E, w=0, -k\frac{\partial T}{\partial r}=h_f\left[T_f-T\right], \tag{7}$$

$$-D_B\frac{\partial C}{\partial r}=h_m\left[C_f-C\right]\ at\, r=R_1, \tag{8}$$

$$u\to 0, v\to 0, T\to T_\infty, C\to C_\infty, N\to N_\infty \text{ as } z\to\infty. \tag{9}$$

The following similarity transformations are used to reduce the system of PDEs into ODEs:

$$u=2azf', v=Eg, w=-aR_1\frac{f}{\eta^{1/2}}, \tag{10}$$

$$\theta=\frac{T-T_\infty}{T_w-T_\infty}\ at\ CWT, \theta=\frac{T-T_\infty}{b_z}\ at\ PST, \tag{11}$$

$$\phi=\frac{C-C_\infty}{C_w-C_\infty},\chi=\frac{N-N_\infty}{N_w-N_\infty},\eta=\frac{r^2}{R_1^2}. \tag{12}$$

Now substituting (10)-(12) into the Equations (2)-(6), we get

$$\eta f'''+f''+\mathrm{Re}\, ff''-\mathrm{Re}\, f'^2-\beta_1\mathrm{Re}(\frac{f^2f''}{\eta}+2f^2f'''-2fff'')-\mathrm{MRe}(\frac{f'}{2}-\beta_1 ff'')+\lambda\left(\theta-Nr\phi-Nc\chi\right)=0, \tag{13}$$

$$2\eta^2g''+2\eta g'-\frac{g}{2}+2\mathrm{Re}\, fg'+\mathrm{Re}\, fg-M\,\mathrm{Re}(\eta g-2\eta\beta_1 fg'-\beta_1 fg)-\beta_1\mathrm{Re}(2f^2g'+4ff'g-4\eta f^2g''+\frac{4f^2g'}{\eta})=0 \tag{14}$$

$$(1+Rd)(\eta\theta''+\theta')+\mathrm{RePrf}\,\theta'+\mathrm{Pr}\,Nb\eta\theta'\phi'+\mathrm{Pr}\,Nt\eta\theta'^2+\mathrm{Pr}\,\delta\,\mathrm{Re}\,\theta+\mathrm{Pr}\,\mathrm{Re}\,M(Ec_1f'^2+Ec_2g^2)=0\,, \tag{15}$$

$$\eta\phi''+\phi'+\mathrm{Re}\,\mathrm{Pr}\,Lef\phi'+Le\,\mathrm{Pr}\frac{N_t}{N_b}\theta'+Le\,\mathrm{Pr}\frac{N_t}{N_b}\eta\phi''=0 \tag{16}$$

$$\chi''+\frac{1}{\zeta^{\frac{1}{2}}}Lb\,\mathrm{Re}\,f\chi'+\frac{1}{2\zeta}\chi'-Pe\left[\phi'\chi'+\left(\Omega+\chi\right)\phi''\right]=0 \tag{17}$$

here, λ_1 denotes the relaxation to time parameter constant, ν be the kinematic viscosity, $\left(T,C\right)$ are the Nano liquid temperature and volume friction, respectively, β be the thermal expansion coefficient, typical measurements of volume microbes is γ, ρ_p,ρ_m be the nanoparticles density and density of microorganisms, τ conveyed the proportion of nominal hotness capability of Nano-material's to thermal capacity of the base fluid, α_1 be the current diffusivity, $\left(\rho_f,c_f\right)$ indicates the liquid density and capacitance of fluid correspondingly, D_B, and D_T be the coefficients of Brownian motion and thermophoresis diffusion respectively, B_0 be the magnetic field strength, electric conductivity is denoted by σ and b be the chemo taxis relentless, W_c be the cell swaying quickness and h_f be the convective heat transmission factor, h_m be the concentration transmission factor, and h_n microorganism transmission factor.

here β_1 be the fluid parameter, Re,M be the Reynolds amount and compelling factor λ,Nr,Nc are mixed convection, flexibility proportion parameter, bio convection Rayleigh numeral and Pe, Ω, Lb, are the Pacolet number, Lewis number and dimensionless values are also given.

$$\mathrm{Re}=\frac{aR_1^3}{2r},\ Lb=\frac{\nu}{D_m},\ \Omega=\frac{N_\infty}{\left(N_w-N_\infty\right)},$$
$$Pe=\frac{bW_c}{D_m},\ \mathrm{Re}=\frac{aR_1^2}{2\nu},\ \beta_1=\lambda_1 a,$$
$$M=\frac{\sigma\beta_0^2}{\rho a},\ \beta_1=\lambda_1 a,\ \lambda=\frac{Gr}{Gr^*},$$
$$Nr=\frac{Gr}{Re_z^2},\ Nc=\frac{Gr}{Gr^{**}},\ Gr=\frac{g\beta\left(T_w-T_\infty\right)z^3}{\nu^2},$$
$$Gr^*=\frac{g\left(C_w-C_\infty\right)z^3}{\nu^2},\ Gr^{**}=\frac{g\left(N_w-N_\infty\right)z^3}{\nu^2}$$

Results

we discussed the graphical result of different parameter β_1, Re,M, λ,Nr,Nc, Pe, Ω and Lb, on velocity, fluid temperature, fluid concentration. The linear equation combine with boundary and initial value problem is solved by using the bvp4c technique on MATLAB.

The graphical representation of velocity, concentration, fluid temperature, density of motile microorganism is presented below:

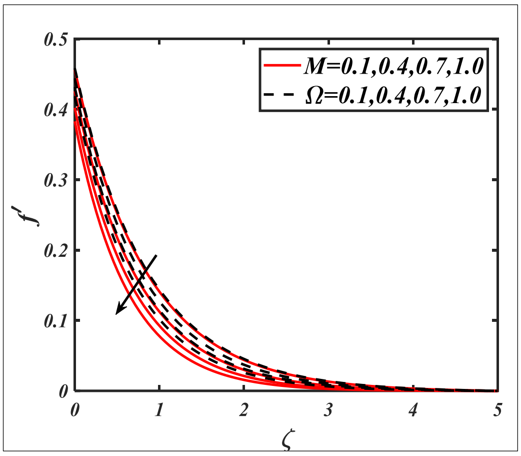

Fig 3: Variations of f' for M & Ω

The consequences of magnetic factor M and Ω on the velocitcal concentrations f' are demonstrated in Fig. 3. The curvatures, it is perceived which is rising estimation of both factors' magnetic factor and Ω reduces the velocity concentration. Lorentz forces are resistive forces engaged in the Magnetic field and other forces. As the magnetic factor M improves, the Lorentz-force is raising that opposes the liquid flow due to which the velocities decay and the temperature and microorganism have increased.

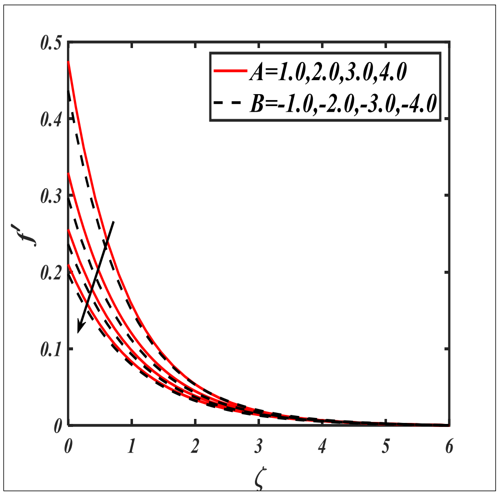

Fig 4: Variations of f' for A & B

The upshots of A, B against velocity distribution f' are considered in Fig. 4. The velocity sketch falls as we see the rising evaluation of both parameters A and B.

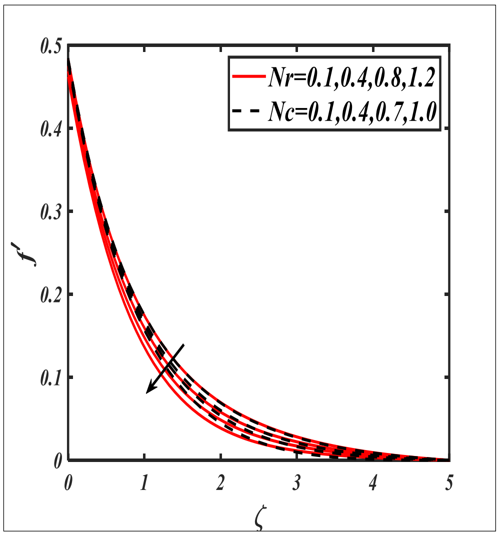

Fig 5: Variations of f' for Nr & Nc

Fig. 5 shows the characteristics of Nr and Nc against the velocity disseminations f'. The results elaborate that the improving values of the both factors decay the velocity concentration of the fluid flow f'.

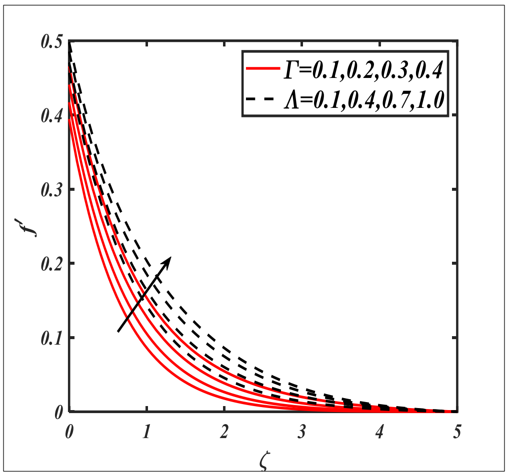

Fig 6: Variations of f' for $\Gamma \& \Lambda$

The nature of the Λ and Γ for the velocity concentration of nanomaterial's of the fluid is elaborated in Fig. 6. The amplification in the values of the both factor Λ and Γ retards the velocity distributions.

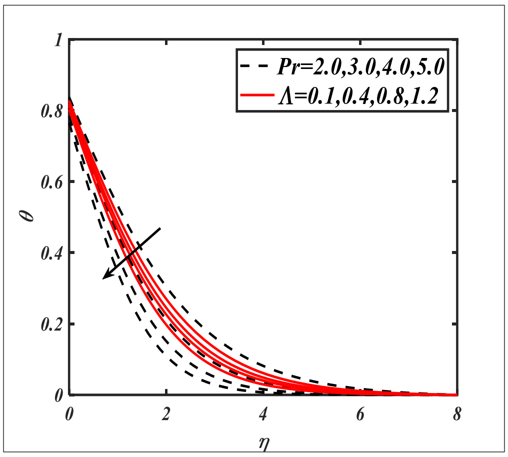

Fig 7: Variations of θ for $\mathrm{Pr} \& \Lambda$

To reveals the impact of prenatal number and Λ on the temperature field θ the Fig. 7 is plotted. The curves of temperature concentration θ are easily improved with an improvement in values of Prenatal number Pr and Λ

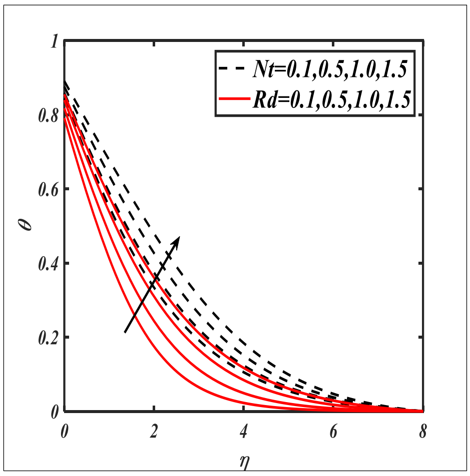

Fig 8: Variations of θ for $\mathrm{Nt} \& \mathrm{Rd}$

In Fig. 8 the behavior of thermo-pharoses factor Nt and current emission Rd on the temperature dissemination θ are deliberated. From the figure it can be observed that the temperature concentration is boost up by the escalating variation of both parameters the thermo-pharoses factor Nt and thermal-wave emission.

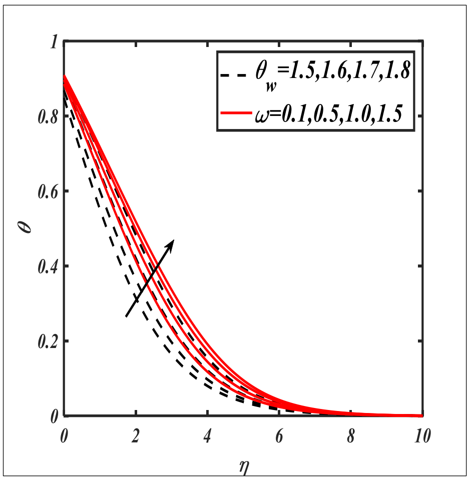

Fig 9: Variations of θ for θ_w & ω

The prominent features on temperature concentrations of both temperature ratio parameter and ω are depicted in Fig. 9. The high temperature concentration of the nano-material diminishes with the advanced estimation of the both ω and temperature proportion factor.

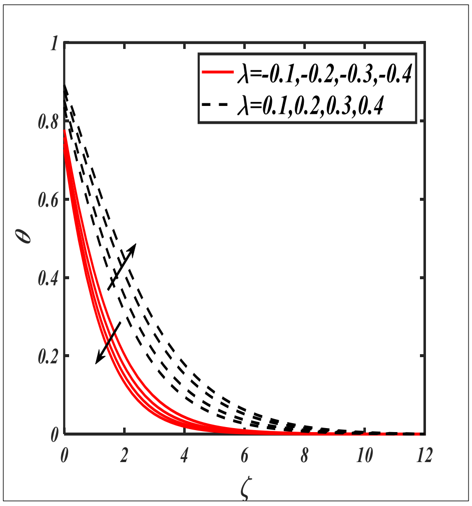

Fig 10: Variations of θ for λ & $-\lambda$

In Fig. 10 the impacts of λ for temperature profile θ are reflected**.** For the positive values of the λ, the temperature concentration of nanoparticles boosted while it shows opposite nature for negative values of λ .

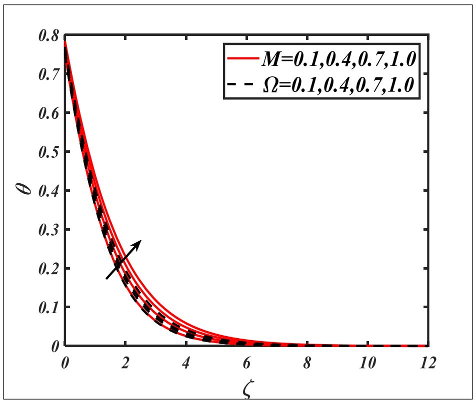

Fig 11: Variations of θ and M & Ω

Fig. 11 expounded to expose the possessions of magnetic factor M and Ω on the temperature concentration θ. For graters the standards of magnetic factor M and Ω the temperature concentration profile boosted.

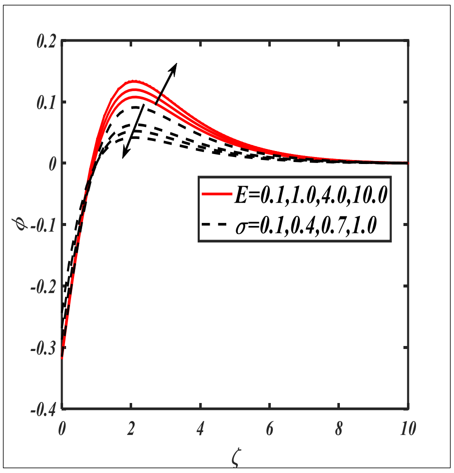

Fig 12: Variations of ϕ for $E \,\&\, \sigma$

Fig. 12 exposes the stimulus of initiation energy E and σ on concentration field ϕ. From the figure it is apparent that the concentration profile improved for swelling disparity of activation energy while incompatible performance for σ.

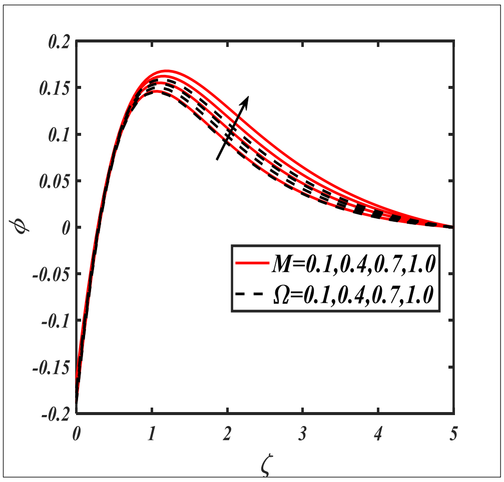

Fig 13: Variations of ϕ for $\mathrm{M} \,\&\, \Omega$

Fig. 13 is capture to advert the influences of magnetic factor M and Ω on the volumetric concentration field ϕ. The curve reflects that the volumetric concentration field positive nature for exhilarating valuation of both factors.

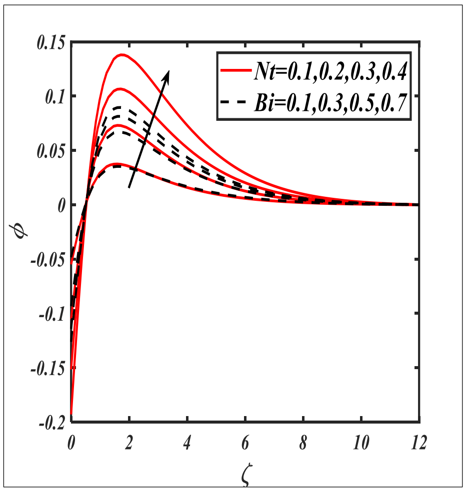

Fig 14: Variations of ϕ for $Nt \,\&\, Bi$

The deviation of thermo-phoresis factor Nt and Biota number Bi for concentration of nano-material of fluid is delineated in Fig. 14. This shows that the concentration profile boosted for increasing values of both parameters' thermophoresis factor and biota no.

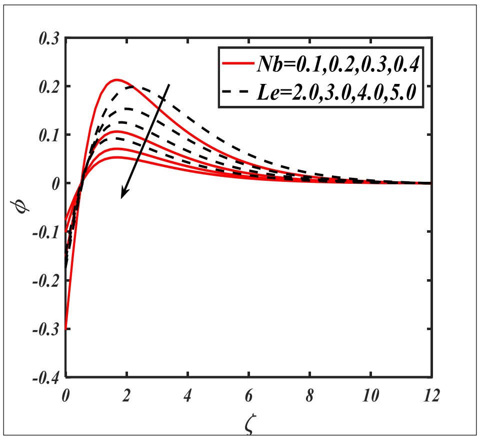

Fig 15: Variations of ϕ for $Nb \& Le$

The salient structures of Lewis number Le and Brownian gesture factor Nb versus volumetric concentration are plotted in Fig. 15. The concentration profile of nano-material condenses for elevated values of both parameters Lewis number Le and Brownian motion factor Nb.

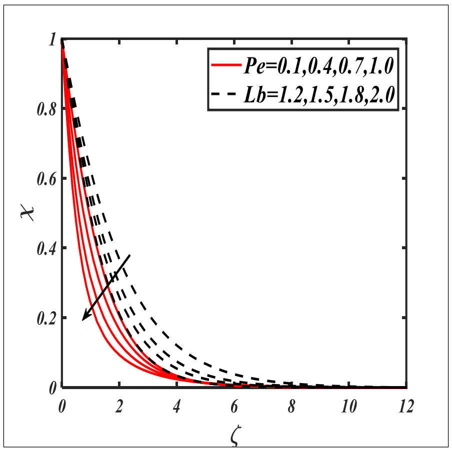

Fig 16: Variations of χ for $Pe \& Lb$

Fig. 16 determines the environment of bio convection Lewis number Lb and Pacolet number Pe for motile microbe's concentration χ. The concentration of motile microbes falls for amplifying values of both parameter bio convection Lewis number and Pacolet number. Such a inclination is related owing to the fact that Pe conquered converse relation with microorganism diffusivity due to which motile
Micro-organism's concentration declines.

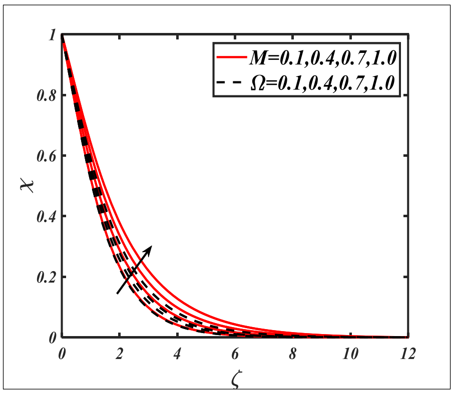

Fig 17: Variations of χ and M & Ω

The consequences of magnetic parameter and Ω for micro-organism's concentration field χ are deliberated in Fig. 17. The growing values of both factors' magnetic factor and Ω intensified the microbe's concentration.

Conclusion

The main purpose of this work is to examine the behavior of bio convection on rate-type Nano fluid containing solid particles and microorganisms over a cylinder. The significance of thermophoresis and Brownian diffusion is analyzed for Nano fluid. Here the Niels convective boundary conditions are used to estimate the flow phenomenon. The main concluding remarks of work are summarized below:

- The presence of magnetic parameter declines the velocity field.
- Highly motley convection factor boosts the flow of fluid.
- The large values of bio convection Rayleigh number reduce the field of velocity.
- Heat transfer rate is boosted up with greater thermal radiation and thermophoresis parameter.
- The temperature ratio parameter raises the temperature of fluid.
- The growing value of activation energy and thermophoresis parameter raises the concentration of Nano fluid.
- The larger Lewis number declines the concentration of Nano fluid.
- Microorganism's field is depressed by growing Pacolet number.
- Micro-organisms field is decline for larger bio convection Lewis number.

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