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A COMPUTATIONAL MODEL FOR THE DENSITY OF MOTILE MICROORGANISMS IN THE CASSON FLUID FLOW WITH THERMAL RADIATION

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Abstract:

Density of motile microorganisms shows a dynamic character in alleviating and monitoring the momentum, thermal and solutal boundary layers. In sight of this, we inspected the flow features on the suspensions of motile microorganisms in the Casson nanofluid due to stretching of a sheet. The impact of radiation, non-uniform heat sink or source, thermophorsis and Brownian motion are studied. The flow is laminar and time dependent. The joint influence of heat and mass transfer features are examined. The velocity slip boundary condition is deemed to investigate the flow features. The modeled equations are highly coupled and nonlinear. So, analytical solution for this model is not possible. Hence, we presented a numerical solution. Suitable similarities are pondered to metamorphose the original PDEs into ODEs and then solved by utilizing Runge-Kutta based shooting technique. Influences of varied parameters on the flow fields are discussed in detailed with the aid of graphs. Simultaneous elucidations are bestowed for both Newtonian and non-Newtonian fluids. It is depicted that an enhancement in the thermophoresis parameter results an enhancement in the heat thereby a reduction in concentration. Further, it is characterized that bio convection Lewis number and Peclet number have a reducing behaviour of density of motile microorganisms.

***Keywords*:** MHD, heat and mass transfer, Bio-convection, Casson fluid, Brownian motion.

1. Introduction:

Bioconvection is the word used in designates the sensation of macroscopic preservation persuaded by the collective motion of a huge quantity of self-forced motile microorganisms like bacteria, flagellate, protozoa ciliate, and the planktonic larvae of certain invertebrates. Density of motile microorganisms shows a dynamic charm in alleviating and monitoring the momentum, thermal and solutal boundary layers like wine creation chore, making of foodstuff, chemical processing, extrusion process, fuel cell technology and bio-reactors. The purpose of these models is to find out which microorganisms are better for absorbing CO_2.Alloui*et al.* (2007) studied the flow and heat transfer features on bioconvective flow over a thin layer. An analytical method is use get an exact solution of the problem. The influence of thermic heat on chemically reacting nanofluid owing to motile microorganisms was demonstrated by Ramzan *et al.* (2017). Shafiq *et al.* (2017) discussed the bioconvective flow, heat and mass transport features of Newtonian liquid motion across a stretched sheet in the presence of thermophoresis. Ananthakumar *et al.*(2018) studied the impact of Peclet number on MHD flow over a sheet and found that density of motile microorganisms is reduced. Impact of thermic heat and convection on a time-dependent mixed convective flow across a sheet in the conducting fields was discussed by Irfan *et al.* (2020). The work conducted by Li *et al.* (2023) contracts with the combined stimuli of activation energy, couple stress and chemical response on Bioconvective nanofluid across a stretched surface. Recently, Jeevankumar and sandeep (2024) reported the thermal diffusion features of a time-dependent shear thickening liquid flow past an elongated surface.

Manufacturing and built-up measures deeply trusted on shear thickening liquids while also practiced in everyday life viz.: dyes, apple pulp, honey, ketchup, organic solutions with low acerbic rate, etc. The liquids that do not performance upon the Newtonian's law is termed Non-Newtonian liquid. The flow of shear thickening liquids owing to a strained exterior has many solicitations in trade practice like glue movement in tunnel filling and drilling liquid stream when a break is met thru piercing. Owing to this Rivlin (1948), Sarpkaya (1961), Rajagopal (1982), Pinho and Whitelaw (1990), Sandeep *et al.* (2015) and Kempannagari *et al.* (2020) are concentrating to examine the impact of heat transport on shear thickening liquids. Khan *et al.* (2022) presented a methodical resolution to 2D MHD shear thickening Casson liquid movement with the aid of HAM. Further,

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Nayak *et al.* (2022) and Kumar *et al.* (2023) paid their interest to inspect the heat transfer aspects of an electrically conducting flow past a stretching sheet. Newly, Snadeep *et al.* (2024) presented a numerical study to examine the non-Newtonian nanofluid characteristics in the presence of irregular heat source/sink and concluded that the shear thickening parameter has a tendency to diminution in the rate of thermic transport.

A nanofluid is the combination of the base fluid such as water H_2O, $C_2H_6O_2$ and Oils with nanometer sized particles of Cu, Zn, Si, Ti, etc. It is usually presumed that nanoparticles surge the heat transmission recital of nanofluids. The solicitations of nanofluids in abundant scientific and industrial arenas made scholars attraction their devotion to using nanofluids in automatic, biomedical and organic microsystems like combustion, coolants, thread plastics and numerous polymer developments. Choi (1995) suggested the clue of nanoliquids in 1995 to surge thermal transport proportions. Scientists (Khan and Pop (2010), Chamkha and Aly (2010), Mustafa *et al.* (2011), Nadeem *et al.* (2014) and Ashwinkumar *et al.* (2021)) examined the convective nanofluid flow due to sundry surfaces with various thermal transport features. Jamshed *et al.* (2021) analysed the outline aspects of nanofluids over a slippery external with the aid of Keller Box method. Amjad*et al.* (2022) deliberate the sway of Brownian moment on convective flow due to an exponential surface by using the amended Fourier's law and originate that the function of heat augments for amassing values of Brownian parameter. Recently, investigators (Sandeep and Ashwinkumar (2022), Ahmad *et al.* (2023), Endalew and Sarkar (2023), Aashwinkumar (2023), Hussain *et al.* (2023))concentrated on the research of hyperbolic nanofluid flow owing to stretched sheet with thermophoresis and Brownian moment.

In light of the afore works, it is vibrant that no efforts have been made to examine the flow features on the suspensions of motile microorganisms in the Casson nanofluid due to stretching of a sheet with primary velocity slip. The stimulus of thermic heat, irregular heat sink or source, thermophorsis and Brownian motion are studied. The modeled equations are highly coupled and nonlinear. So, analytical solution for this model is not possible. Hence, we presented a numerical solution. Influences of varied parameters on the flow fields are discussed in detailed with the aid of graphs. Simultaneous elucidations are bestowed for both Newtonian and non-Newtonian fluids.

2. Formulation:

We supposed a two-dimensional forced convective bio-convection and slip flow of Casson liquid through a stretched sheet with thermophoresis Brownian moment. Impact of chemical reaction, variable heat sink or source and radiative heat are considered. The sway of Reynolds number and induced resistive forces are negligible. Assume that $u_w(x) = ax$ is the fluid velocity nearby the sheet. A constant magnetic force $B = B_0$ is applied in the way of $y-$axis as depicted in Fig. 1.

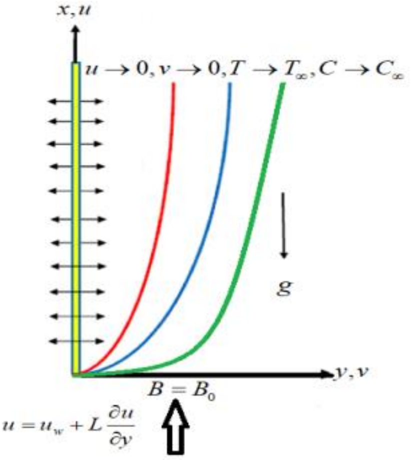

Fig. 1: Flow geometry

Based on the assumptions, the governing equations of the model are (see Anantha Kumar *et al.* (2018), Irfan *et al.* (2020) and Kempannagari *et al.* (2020))

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0, \tag{1}$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\upsilon_f\left(1+\beta^{-1}\right)\frac{\partial^2 u}{\partial y^2}-\frac{\sigma B_0^2}{\rho_f}u+g\rho_f\left(\beta_T(T-T_\infty)+\beta_C(C-C_\infty)\right), \tag{2}$$

$$\left(\rho C_p\right)_f\left(uT_x+vT_y\right)=\left(k_f+\frac{16\sigma^* T_\infty^3}{3k^*}\right)T_{yy}+q^*+\tau T_y\left(D_B C_y+\frac{D_T}{T_\infty}T_y\right), \tag{3}$$

$$uC_x+vC_y=D_m C_{yy}-k_1(C-C_\infty)+\frac{D_T}{T_\infty}T_{yy}, \tag{4}$$

$$uN_x+vN_y=D_n N_{yy}-\frac{bW_c}{N_s-N_\infty}\left(NC_y\right)_y, \tag{5}$$

Here $u,v,\upsilon,\beta,\sigma,g,\rho,\beta_T,\beta_C,k,\sigma^*,k^*,\tau,C_p,D_B,D_T,D_m,D_n,k_1,b\,\&\,W_c$ are respectively, velocity components, kinematic viscosity, Casson parameter, electrical conductivity, gravitational force, density, thermal and solutal expansion coefficients, thermal conductivity, Stefan-Boltzmann constant, mean absorption coefficient, ratio of heat capacity, heat capacitance at constant pressure, Brownian and thermophoretic diffusivity coefficients, diffusivity of mass and microorganisms, chemical parameter, b is the chemotaxis invariable and W_c is the supreme rapidity of the swimming cell.

Define $$q^*=\frac{a\left(T-T_\infty\right)k}{\upsilon}\left(A^*\frac{\left(T_w-T_\infty\right)}{\left(T-T_\infty\right)}f'+B^*\right), \tag{6}$$

Here $A^*,B^*<0$ and $A^*,B^*>0$ specifies the internal heat sink and source respectively.

The related BCs are (see Anantha Kumar *et al.* (2018), Irfan *et al.* (2020) and Kempannagari *et al.* (2020))

$$\left.\begin{array}{ll} u=u_w+L\dfrac{\partial u}{\partial y},v=0,T=T_w,C=C_w,N=N_w, & at\,y=0,\\ u\to 0,v\to 0,T\to T_\infty,C\to C_\infty,N\to N_\infty, & as\,y\to\infty, \end{array}\right\} \tag{7}$$

Here L is molecular free mean path.

Consider,

$$\eta=\sqrt{\frac{a}{\upsilon}}y,u=axf'(\eta),v=-\sqrt{a\upsilon}f(\eta)\theta(\eta)=\frac{T-T_\infty}{T_w-T_\infty},\phi(\eta)=\frac{C-C_\infty}{C_w-C_\infty},\chi(\eta)=\frac{N-N_\infty}{N_w-N_\infty} \tag{8}$$

Where $\eta,f',\theta,\phi\,\&\,\chi$ are similarity variable, dimensionless velocity, temperature, Concentration and density of motile microorganisms.

From Eqn. (8), Eqns. (2) - (4) yield

$$\left(1+\beta^{-1}\right)f'''+ff''-\left(f'\right)^2+Gr_T\theta+Gr_C\phi-Mf'=0, \tag{9}$$

$$\left(1+Rd\right)\theta''+\Pr f\theta'-\Pr f'\theta+A^*f'+B^*\theta+\Pr\theta'\left(N_b\phi'+N_t\theta'\right)=0, \tag{10}$$

$$\phi''+Le\Pr\left(f\phi'-f'\phi\right)-K_r Le\Pr\phi+\frac{N_t}{N_b}\theta''=0, \tag{11}$$

$$\chi''-Pe\left(\phi''+(\chi+S)\chi'\phi'\right)+Lb\Pr\left(f'\chi+f\chi'\right)=0, \tag{12}$$

The altered boundary conditions are

$$\left.\begin{array}{ll} f'=1+\gamma f'',f=0,\theta=1,\phi=1,\chi=1, & at\,\eta=0,\\ f'(\eta)\to 0,\theta(\eta)\to 0,\phi(\eta)\to 0,\chi(\eta)\to 0, & as\,\eta\to\infty, \end{array}\right\} \tag{13}$$

Here $Gr_T = \dfrac{g\beta_T\left(T_w - T_\infty\right)}{a^2 x}$ is thermal Gtashof number, $Gr_C = \dfrac{g\beta_C\left(C_w - C_\infty\right)}{a^2 x}$ is solutal Grashof number, $M = \dfrac{\sigma B_0{}^2}{a\rho_f}$ is magnetic parameter, $Rd = \dfrac{16\sigma^* T_\infty{}^3}{3kk^*}$ is radiation parameter, $\Pr = \dfrac{\left(\upsilon\rho C_p\right)_f}{k_f}$ is Prandtl number, $N_b = \dfrac{\tau D_B\left(C_w - C_\infty\right)}{T_\infty(\mu C_p)_f}$ is Brownian parameter, $N_t = \dfrac{\tau D_T\left(T_w - T_\infty\right)}{T_\infty(\mu C_p)_f}$ is thermophoresis parameter, $Le = \dfrac{\alpha}{D_m}$ is Lewis number, $K_r = \dfrac{k_1}{a}$ is chemical reaction parameter, $Pe = \dfrac{bw_c}{D_n}$ is Peclet number, S is the parameter of microorganisms concentration difference, $Lb = \dfrac{\alpha}{D_n}$ is the bio convection Lewis number and $\gamma = L\sqrt{\dfrac{a}{\upsilon}}$ is the wall thickness parameter.

The significant physical quantities of attention in this report are friction factor, local heat and mass transport rates that are C_f, Nu and Sh respectively.

In nondimentional form these are defined by

$$C_f \,\mathrm{Re}_x^{\frac{1}{2}} = \left(1+\beta^{-1}\right) f''(0), Nu\,\mathrm{Re}_x^{\frac{-1}{2}} = -\left(1+Rd\right)\theta'(0), Sh\,\mathrm{Re}_x^{\frac{-1}{2}} = -\phi'(0), \mathrm{Nn}\,\mathrm{Re}_x^{\frac{-1}{2}} = -\chi'(0), \quad (14)$$

Here the local Reynolds number is $\mathrm{Re}_x = \dfrac{xu_w}{\upsilon}$.

3. Results and Discussion:

The set of Eqs. (9)-(12) are nonlinear and highly coupled ODES. The analytical solution is not possible for this. Runge-Kutta based shooting technique is exploited to crack the coupled ODEs with the help of boundary conditions. The impact of sundry parameters on the flow fields are scrutinized through graphs. In the graphs, solid and dashed lines indicate the non-Newtonian and Newtonian fluids.

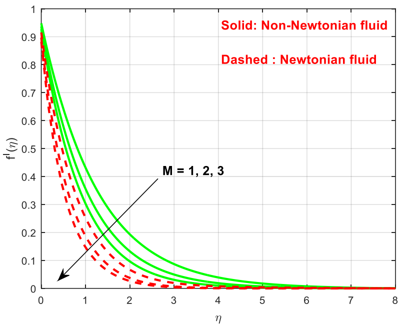

Fig. 2: Impact of M on f'

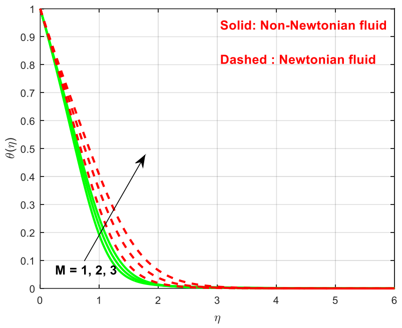

Fig. 3: Impact of M on θ

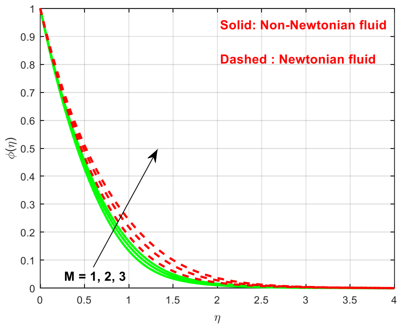

Fig. 4: Impact of M on ϕ

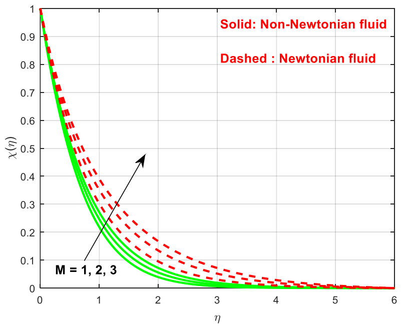

Fig. 5: Impact of M on χ

Figs. 2-5 are sketched to see the behaviour of magnetic field parameter on the distribution of velocity. An increase in M results a decrement in velocity and an enhancement in temperature, concentration and the density of motile microorganisms are noticed due to the Lorentz force.

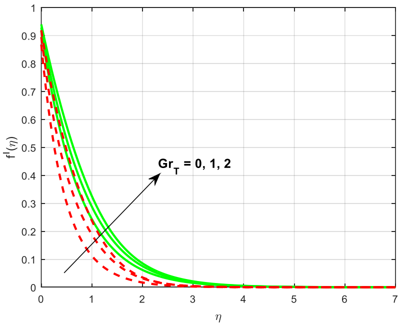

Fig. 6: Impact of Gr_T on f'

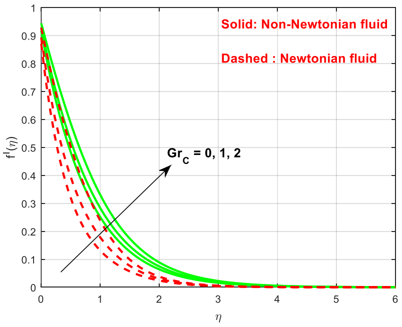

Fig. 7: Impact of Gr_C on f'

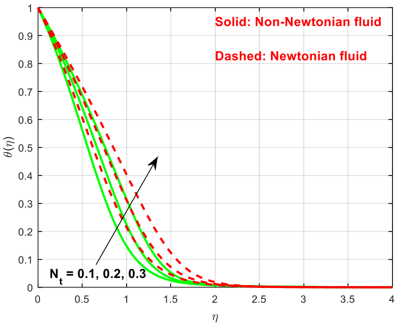

Fig. 8: Impact of N_t on θ

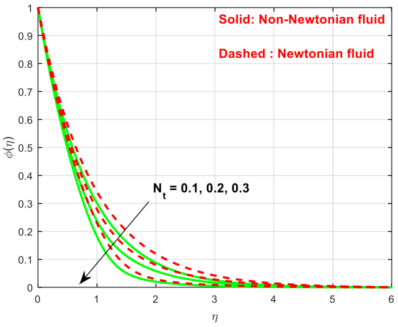

Fig. 9: Impact of N_t on ϕ

Figs. 6 and 7 show the impact of thermal and solutal Grashof numbers on velocity. It is illustrated that, for both the cases the fluid velocity enhances for n augmentation in Gr_T and Gr_C .

The impression of N_t on $\theta(\eta)$ and $\phi(\eta)$ is outlined in figs. 8 and 9. For the heightening values of N_t, the heat is upsurge with the consolidation of N_t where as a undesirable result is illustrious in the concentration.. For the superior N_t origins the escalation in the ratio of nanoparticles, eventually the curves of $\theta(\eta)$ upgraded. Fig. 10 and 11 portrays the consequence of N_b versus $\theta(\eta)$ and $\phi(\eta)$. It is detected from the displays that both heat and concentration functions are inflamed. Actually, for the various nanoparticles have distinct values of N_b . Strengthening of Brownian motion causes to enhance the fluid temperature and concentration simultaneously.

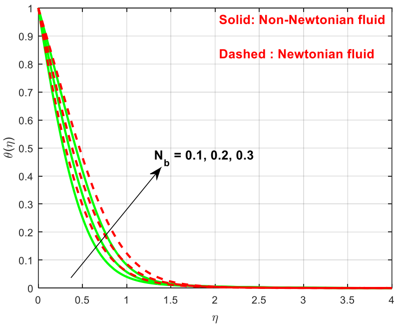

Fig. 10: Impact of N_b on θ

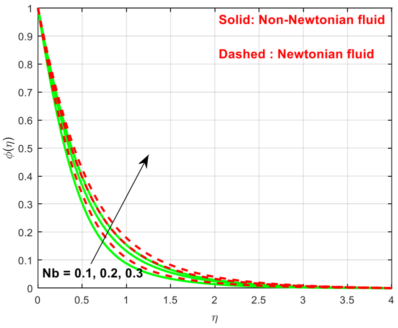

Fig. 11: Impact of Nb on ϕ

Figure 12 shows the significance of radiation parameter on heat function. It is seen that, $\theta(\eta)$ enhances for increasing values of radiation parameter. Physically, increasing values of R generates heat energy in the flow which causes an enhancement in $\theta(\eta)$. The impact of Peclet number and bio convection Lewis number on $\chi(\eta)$ is depicted in Figs. 13 and 14. We observe from the graph that a decrement in the curves of $\chi(\eta)$ for an enhancement in Pe and Lb in both the cases.Figure 15 is sketched to see the nature of chemical reaction parameter on the curves of $\phi(\eta)$. It was noticed that, $\phi(\eta)$ decreases for improving values of Kr.

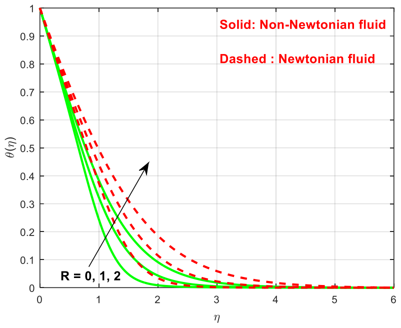

Fig. 12: Impact of R on θ

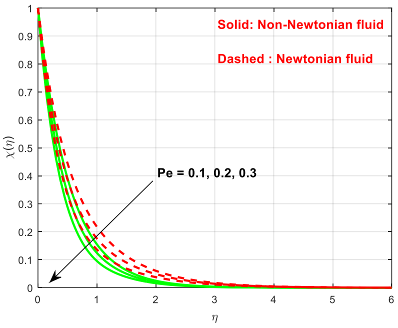

Fig. 13: Impact of Pe on χ

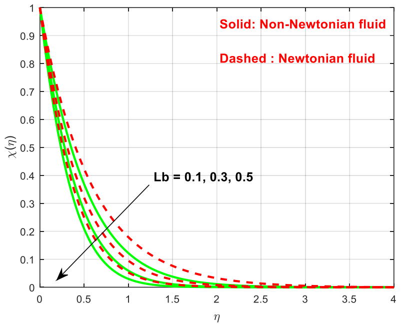

Fig. 14: Impact of Lb on χ

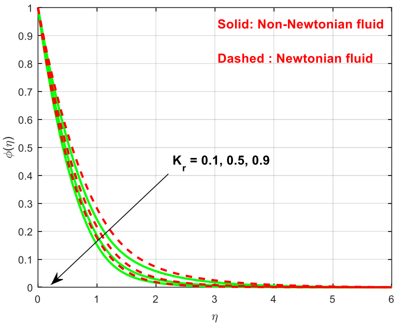

Fig. 15: Impact of K_r on ϕ

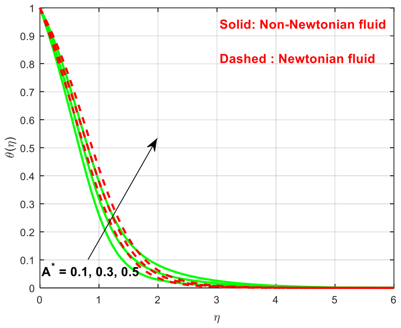

Fig. 16: Impact of A^* on θ

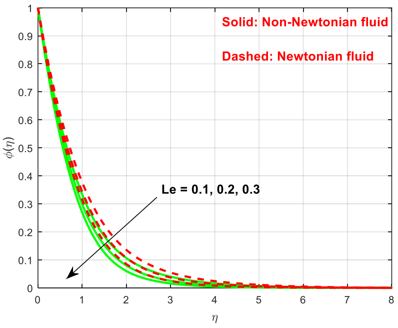

Fig. 17: Impact of Le on ϕ

Figure 16 is portrayed to see the influence of non-uniform heat source/sink parameter on temperature. It is obtained from the figure that, an enhancement in A^* results a hike in fluid temperature. Physically, A^* acts as heat source in the flow and hence the $\theta(\eta)$ temperature is increased. Fig. 17 demonstrates the influence of Le on the curves of concentration. It is seen from the display that $\phi(\eta)$ reduces with the intensification of Lewis number. The proportion within thermal and mass diffusivities is identified as Lewis number. Thus the mass diffusivity is abridged with the amplification of Le hence $\phi(\eta)$ is weakened.

4. Conclusions

The joined stimulus of heat and mass transfer features on the suspensions of motile microorganisms in the Casson nanofluid due to stretching of a sheet was examined. The modelled equations are highly coupled and nonlinear. Suitable similarities are pondered to metamorphose the original PDEs into ODEs and then solved by utilizing R.K. based shooting technique. Influences of varied parameters on the flow fields are discussed in detailed with the aid of graphs. Simultaneous elucidations are bestowed for both Newtonian and non-Newtonian fluids.

The main findings are

- An augmentation in magnetic field parameter results a hike in temperature, concentration and density of motile microorganisms but an opposite behaviour is noticed in velocity distribution due to Lorentz force.
- The influence of Pe, Le and Lb causes a diminution in the density of motile microorganisms
- Dwindling in concentration is perceived for increasing values of chemical reaction parameter.
- Increasing values of thermophoresis and Brownian motion parameters causes an enhancement in temperature.
- Non-uniform heat source or sink parameters acts as heat source in the fluid flow.

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