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Research Article

Bioconvection Flow in the Presence of Casson Nanoparticles on a Stretching/Shrinking Vertical Sheet with Chemical Reaction

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A Casson nanoparticle is used in this study to investigate the effects of toxic reactions, temperatures, and concentrations on convective heat transfer flow across a stretching/shrinking vertical sheet. The goal is to convert the control linear partial differential equations (PDEs) into an ordinary differential equations (ODEs) set and analyses them statistically using the Bvp4c technique in MATLAB software. It is necessary to look how various variables, such as the Casson nanofluid measurement, the chemical change constants and Prandtl numbers, the concentration-thermal-buoyancy ratio, the microorganism-to-thermal-buoyancy rate of return, the Lewis number, and other bioconvection-related parameters (such as the variation in micro-organism concentration and the buoyancy parameter), affect each other. The numerical results of the velocity, temperature, concentration, and bioconvection flow profiles are displayed.

1. Introduction

Due to various outstanding thermal conductivities, nanofluids are now used as working fluids instead of base fluids. Choi [1] was the first one to discover nanofluids, which are having a concentration of nanosized particles. According to Lee et al. [2], nanofluids have superior heat transmission properties as compared to basic fluids. Many industrial and technological applications exploit non-Newtonian nanofluids, such as embedded polymers, biological remedies, paints, asphalts, and glues. Nanofluids are manufactured by suspending nanoparticles which include nitrides, carbon nanotubes, and metal carbides in warm trading fluids; the lukewarm conductivity of these liquids is contingent on the sparkle trade coefficient between the vivacity trade intermediate and the sparkle trade shell. It is found that the non-Newtonian nanofluid has behaved differently on a vertical plate and truncated cone immersed in a porous media. The Casson fluid structure is a combination of non-Newtonian fluid involving applications in food encoding, smelting, excavating, and genetics. In order to mimic the flow properties of pigment oil suspensions, Casson created the Casson nanofluid flow in 1959 [3]. Studies of the Casson fluid or Casson nanofluid flowing in boundary layer thickness across different forms have been conducted by several authors [4–7]. Nanofluids may affect chemical processes, heat production, and MHD radiation across a stretched sheet, according to a number of researchers [8–10]. For many domains of management and innovation, chemical reaction effect is an essential consideration in the study of heat and mass mobility. A chemical reaction between the base liquid and nanoparticles can occur frequently either throughout a phase or at the phase's boundary. Afify [11] has revealed that in the presence of fluid motion and chain reaction, slip boundary conditions influence Casson nanofluid flow across a stretched plate. Bioconvection has demonstrated excellent prospects in the field of environmental sustainable and long-term fuel cell technology. The chemical sensitivity of magneto Casson nanofluids has been researched by Arun et al. [12].

Microorganisms are a generic description of organisms that are too tiny to be identified individually. Bacteria, yeast, viruses, protozoa, and green algae constitute characteristics of microorganisms. Microorganism colonies all ecological niches, in the unfavorable conditions such as engine fuel lines, coal mines, and hot springs where few other living things can persist. Bioconvection emerges when microorganisms migrate upstream in a fluid, culminating in instability and an amorphous pattern. The modular system of such systems required periodic computational geometry optimization in conjunction with laboratory and field testing. Kuznetsov and Avramenko [13] evaluated the bioconvection of gyrotactic microorganisms exploiting nanoparticles for the first time. Hill and Pedley [14] presented a research article on the hydrodynamics of bioconvection. According to Alloui et al. [15], the composition of gravitactic microbes in a cylinder is characterized. Using a dynamic stretching/shrinking sheet, Uddin et al. [16] have evaluated the Stefan blowing phenomena on bioconvection nanofluid flow. The spontaneous bioconvective flow of such a nanofluid containing gyrotactic microorganisms across a projected vertical plate is shown by Chamkha et al. [17]. Mallikarjuna et. al. [18] studied the combined bioconvective flow of nanofluid including gyrotactic microorganisms across a vertical and thin cylinder of nanofluid. The called peristalsis flow of non-Newtonian nanofluid further than the difference of the two infinite coaxial conduits containing swimming oxytactic microorganisms is studied by Abdelsalam and Bhatti [19]. The nondimensionalized governing partial differential equation model is constructed by calculating bioconvection flow and heat transfer in the porous annulus and performance capacity transformations. The results of this analysis demonstrate that after nondimensionalizing microbe guiding equations, the Peclet number initially increases. Ahmad et al. [20] evolved the nonlinear partial differential equations and converted them into dimensionless form using homotopic transformations. They were then analytically explained using the homotopic technique, and they came to the conclusion that the magnetic parameter is responsible for the transformation in both components of velocity. In the horizontal direction, the velocity tends to decrease while the bioconvected Rayleigh number and buoyancy ratio remain stable. It is also acknowledged that increasing the bioconvected Lewis and Peclet numbers results in a decrease in the dispersion of motile microorganisms, but the thermophoresis constant exhibits the opposite propensity.

The impact of major physical parameters discussed numerically in bioconvection flow was explained by Dhanai et al. [21] in their description of the numerical analysis of bioconvection boundary layer flow and heat transfer of electrically conducting nanofluid containing nanoparticles and gyrotactic microorganism over an inclined permeable sheet. The free convective heat transfer from a vertical plate in a porous media saturated with nanofluid under laminar circumstances was explained by Hady et al. [22] to the power-law non-Newtonian flow, and the effects of Brownian motion and thermophoresis are factored in the nanofluid model.

In the presence of bioconvection and chemical reaction effects, Shah et al. [23] illustrate method to quantify the heat transfer attributes of a magneto hydrodynamic Prandtl hybrid nanofluid covering a stretched surface. Across stretching sheets, this article evaluates the bioconvection, inclined magneto hydrodynamic radiations, thermal linear radiations, and chemical reaction of hybrid nanofluid. Additionally, the conclusions are contrasted with nanofluid flow. Also, emphasis is offered to the Prandtl fluid, a non-Newtonian fluid. A few illustrations of real-world implications for hybrid nanofluids encompass microfluidics, business, transportation, the military, and medicine.

The bioconvection effects in Walter's B nanofluid flow are currently explored by Alqarni [24] as a reaction of the stretchable surface, which culminates in important properties such as heat radiation, activation energy, motile microorganisms, and convective boundary restrictions. In graphical and tabular representations, the consequences of interesting parameters on the velocity field, heat field, species concentration, and microbe concentration are displayed. The present strategy is more practical in a variety of domains, including pharmaceutical delivery systems, recombinant proteins, synthetic biology, tissue engineering, and biofuel cells.

With swimming gyrotactic microorganisms in a conjugate mixed bioconvection flow of Carreaunanofluid via an inclined stretchable cylinder with variable magnetic field incidence and binary chemical reaction, Nabwey et al. [25] examine heat transmission. The assessment also considers nonuniform thermal conductivity and stochastic decrease or rise in the heat source. This nano-bioconvection flow example is estimated using a passively controlled nanofluid pattern, which is thought to be more physically accurate than the earlier actively controlled nanofluid typically used. The important discovery of the current study is that the activation energy constraint improves with increasing nanoparticle concentration in the nanofluid.

According to Dhlamini et al. [26], using nanofluids in place of traditional fluids and exploiting motile microorganisms are two methods for moderating the rates of heat and mass transmission. Activation energy, Brownian motion, and thermophoretic effects are only taken into account for the solute and not for the microorganisms in some recent studies of bioconvection flow. The dynamics of the microorganisms are extensively controlled by the activation energy, the thermophoretic force, and Brownian motion.

Different malignant cells can be completely cured with nanoparticles. The most similar therapeutic that sheds light in biomedical science is nanoparticles. Researchers have recently devoted a great deal of attention to the study of nanoparticles due to their structure, shape, low toxicity, and phenomenal compatibility with the human body. A special type of nanoparticle was used to obstruct and kill cancer cells. The gold and Casson nanoparticles among them each had an intended role. Developed specifically nanoparticles were used to injure and kill cancer cells. The problem is tried to pick because it is motivated by this particular application.

2. Mathematical Formulation

Across a semi-infinite moving flat plate, a nanofluid flows in a stable boundary layer in a homogenous free stream. Normal to move, surface coordinates are used to measure the flow. Moreover, the fluid temperature and nanoparticle concentration in the flowing fluid would directly relate to the surface temperature and nanoparticle concentration. Schematic representation of the flow is represented in Figure 1.

The new systems of equations for bioconvection flow are then generated.

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

$$\begin{aligned} u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y} &= u_e\frac{\partial u_e}{\partial x}+\upsilon\left(1+\frac{1}{\beta}\right)\frac{\partial^2 u}{\partial y^2}+(\beta_T)(T-T_\infty)g \\ &\quad +(\beta_c)(C-C_\infty)g+(\beta_N)(N-N_\infty)g, \end{aligned} \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{k}{\rho c_p}\cdot\frac{\partial^2 T}{\partial y^2}+\left(1+\frac{1}{\beta}\right)\frac{\mu}{\rho c_p}\cdot\left(\frac{\partial u}{\partial y}\right)^2, \tag{3}$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_n\cdot\frac{\partial^2 C}{\partial y^2}-k_0(C-C_\infty), \tag{4}$$

$$u\frac{\partial N}{\partial x}+v\frac{\partial N}{\partial y}+\frac{bW_c}{\Delta C}\frac{\partial}{\partial y}\left(N\frac{\partial C}{\partial y}\right)=D_m\cdot\frac{\partial^2 N}{\partial y^2}, \tag{5}$$

where u is component velocity on the x-axis, v is along the y-axis component velocity, υ is kinematic viscosity, β_T is thermal expansion coefficient of temperature, β_c is thermal expansion coefficient of concentration of nanoparticles, β_N is thermal expansion coefficient of density of microorganism, g is buoyancy parameter, N is density motile of microorganism, N_∞ is constant ambient density of microorganism, k is thermal conductivity, (ρc_p) is heat capacity of nanofluid, β is Casson parameter, k_0 is chemical reaction of species with reaction rate constant, D_n is diffusivity of nanoparticles, D_m is diffusivity of microorganism, b is constant velocity of the plate, and W_c is maximum cell swimming speed.

The appropriate boundary conditions are applied to the governing equations (1)–(5):

$$\left.\begin{aligned} v&=0\\ u&=u_w\\ T&=T_w\\ C&=C_w\\ N&=N_w \end{aligned}\right\}\text{at } y=0,$$

$$\left.\begin{aligned} u&\longrightarrow u_e\\ T&\longrightarrow T_\infty\\ C&\longrightarrow C_\infty\\ N&\longrightarrow N_\infty \end{aligned}\right\}\text{as } y\longrightarrow\infty, \tag{6}$$

where N_w is surface density of microorganism.

$$\left.\begin{aligned} u_w(x)&=be^{(x/L)}\\ T_w(x)&=T_\infty+T_0e^{(x/L)}\\ C_w(x)&=C_\infty+C_0e^{(x/L)}\\ N_w(x)&=N_\infty+N_0e^{(x/L)}\\ u_e(x)&=ae^{(x/L)} \end{aligned}\right\}. \tag{7}$$

Using the similarity transformation method, PDE governing equations are generated into ODEs. The followings are the similarity variables which are used as follows:

$$\begin{aligned} \eta &= \sqrt{\frac{a}{2\upsilon L}}be^{(x/2L)}y,\\ \psi &= \sqrt{2a\upsilon L}e^{(x/2L)}f(\eta),\\ u &= ae^{(x/L)}f'(\eta),\\ v &= -\sqrt{\frac{\upsilon a}{2L}}be^{(x/2L)}\left[f(\eta)+\eta f'(\eta)\right],\\ \theta(\eta) &= \frac{T-T_\infty}{T_w-T_\infty};\quad \text{where } T=\theta(\eta)T_0e^{(2x/L)}+T_\infty,\\ \phi(\eta) &= \frac{C-C_\infty}{C_w-C_\infty};\quad \text{where } C=\phi(\eta)C_0e^{(2x/L)}+C_\infty,\\ X(\eta) &= \frac{N-N_\infty}{N_w-N_\infty};\quad \text{where } N=X(\eta)N_0e^{(2x/L)}+N_\infty, \end{aligned} \tag{8}$$

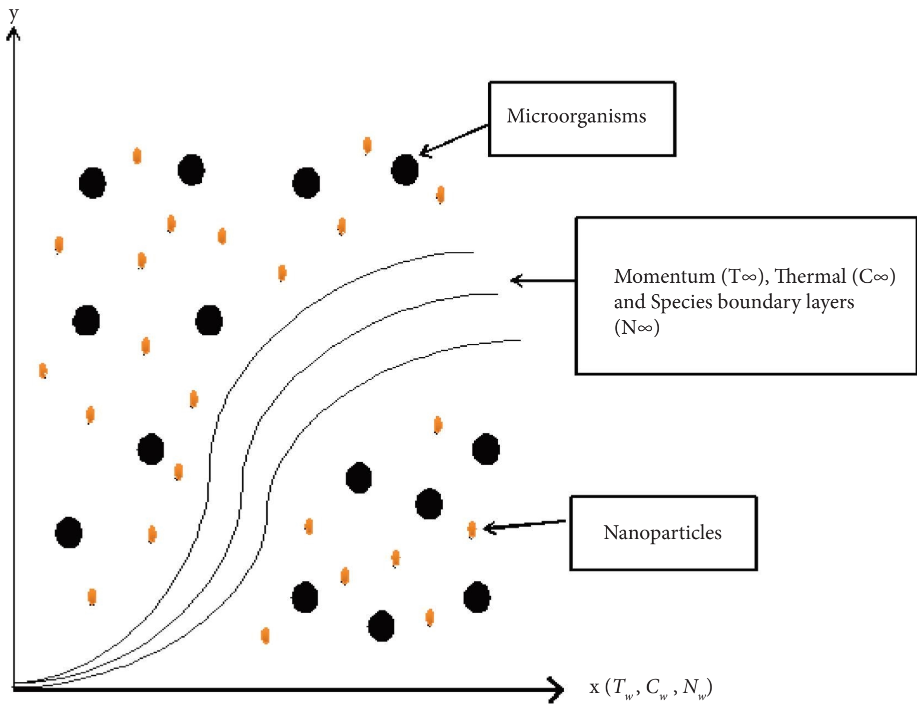

Figure 1: Characteristics of the problem.

where η is similarity variable, with $u = (\partial\psi/\partial y)$ and $v = -(\partial\psi/\partial x)$ symbolizes the stream function, ψ, θ is dimensionless temperature, L is sheet's characteristic length, ϕ is dimensionless nanoparticle fractional function, X is dimensionless microorganisms fractional function, a is constant velocity of stagnation flow, T_0 is constant velocity of temperature, C_0 is constant velocity of concentration, and N_0 is constant velocity of microorganism.

The PDEs are turned into ODEs as follows using the similarity transformation variables:

$$\left(1+\frac{1}{\beta}\right)f'''(\eta) + f(\eta)f''(\eta) - 2\left(f'(\eta)\right)^2 + 2 + 2\lambda\left(\theta(\eta) + \phi(\eta)N_c + X(\eta)N_N\right) = 0, \tag{9}$$

$$4f'(\eta)\theta(\eta) - f(\eta)\theta'(\eta) - \frac{\theta''(\eta)}{P_r} - \left(1+\frac{1}{\beta}\right)E_c\left(f''(\eta)\right)^2 = 0, \tag{10}$$

$$4f'(\eta)\phi(\eta) - f(\eta)\phi'(\eta) - \frac{1}{L_eP_r}\phi''(\eta) + K = 0, \tag{11}$$

$$4f'(\eta)X(\eta) - f(\eta)X'(\eta) - \frac{P_e}{L_bP_r}\left(\phi''(\eta)X(\eta) + \Omega\phi''(\eta) + .X'(\eta)\phi'(\eta)\right) - \frac{1}{L_bP_r}X''(\eta) = 0. \tag{12}$$

In contrast to the boundary constraints,

$$\begin{aligned} f(\eta) &= 0, \\ f'(\eta) &= \varepsilon, \\ \theta(\eta) &= 1, \\ \phi(\eta) &= 1, \\ X(\eta) &= 1 \text{ at } \eta = 0, \end{aligned} \tag{13}$$

$$\begin{aligned} f'(\eta) &= 1, \\ \theta(\eta) &= 0, \\ \phi(\eta) &= 0, \\ X(\eta) &= 0 \text{ as } \eta \longrightarrow \infty, \end{aligned} \tag{14}$$

where $\lambda = (g\beta T_0 L/a^2)$ is mixed convection parameter, $P_r = (\mu C_p/k) = (\upsilon/\alpha)$ is Prandtl number, $L_e = (\alpha/D_n)$ is Lewis number, $P_e = (bW_c/D_m)$ is bioconvection Peclet number, $L_b = (\alpha/D_m)$ is bioconvection Lewis number, $\Omega = (N_\infty/N_w - N_\infty)$ is microorganisms concentration difference parameter, $N_c = (C_0/T_0)$ is concentration to thermal buoyancy ratio parameter, $N_N = (N_0/T_0)$ is microorganism to thermal buoyancy ratio parameter, $E_c = (a^2/C_P T_0)$ is Eckert number, $K = (2k_0 L/a)$ is chemical reaction parameter, and ε is the stretching/shrinking parameter.

3. Results and Discussions

As it is much more feasible in many engineering applications, this study uses a specific BVP to estimate numerical solutions. The governing equations in this analysis are reduced to nonlinear ODEs and numerically solved using MATLAB's bvp4c mathematical solver. MATLAB's bvp4c is used to solve a system of nonlinear ODEs (9) to (12) having boundary conditions (13) and (14).

The obtained results are validated with the already existing results. The validation for physical parameters is given in following Table 1. Numerical values of $-\theta'(0)$ and $-\phi'(0)$ with E_c for $P_r = 4, L_e = 5, P_e = 1, L_b = 1, N_c = 0.1, N_N = 0.1, K = 1,$ and $\Omega = 0.2$.

The values obtained are in good agreement with the already existing work. This shows that the problem is well defined and the formulation of the problem is perfect.

Figure 2 depicts the impression of β on velocity profile, where the velocity profiles decrease for the rising values of β. So the fluid parameter has created on retarding force. This force elevates the viscosity of the fluid despite slowing rapid velocity. The influence β on temperature profile is polled in Figure 3. It is found from Figure 3 that the temperature reduces with an increase in β. Figure 4 depicts the effect of β on concentration profile. It can sight that the concentration decreases in $0 \le \eta \le 0.5$ and increases in $0.5 \le \eta \le 4$ for increasing values of β. Figure 5 illustrates the effect of β on bioconvection flow profile. The profile accelerates for increasing values of β. It is found from Figure 6 that the temperature profile is impeding with an increasing value in E_c. It is noticed from Figure 7 that the concentration profile increases with an increase in K. It is observed from Figure 8 that the concentration distribution amplifies with an increase in L_e. It is found from Figure 9 that the bioconvection flow profile decreases with an increase in L_b.

The bioconvection Peclet number P_e and cell swimming speed W_c are directly proportional with each other and inversely proportional to D_n (microorganism's diffusivity). The bioconvection Peclet number modulates the rates of advection and diffusion. Therefore, a rise in the amount of adventive transport leads to a higher bioconvection Peclet number, which in turn makes the flux of microorganisms to increase quickly. As a response, peak intensity of the bioconvection Peclet number degrades the profile of motile microbe density while increasing the flux of wall motile

Table 1: Comparison of results for $-\theta'(0)$ and $-\phi'(0)$.

E_c	Afify [11] $-\theta'(0)$	Afify [11] $-\phi'(0)$	Present results $-\theta'(0)$	Present results $-\phi'(0)$
0.2	0.655854	1.19213	0.655882	1.19311
0	0.795783	1.113521	0.795698	1.113421
1	0.082093	1.515737	0.082088	1.515682
1.3	−0.139103	1.641030	−0.139179	1.641082

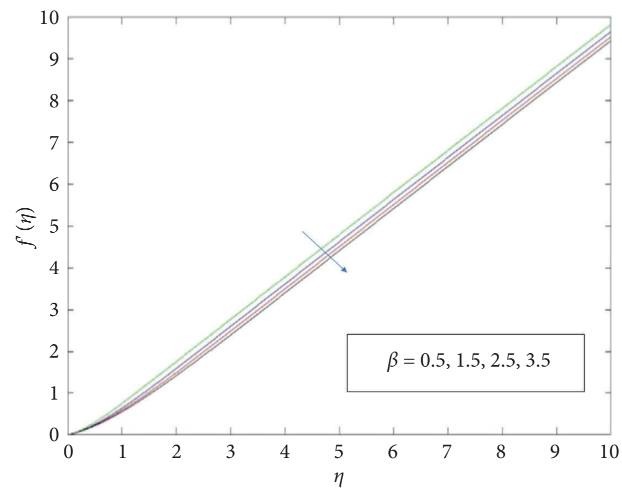

Figure 2: Effect of Casson fluid parameter on velocity profile.

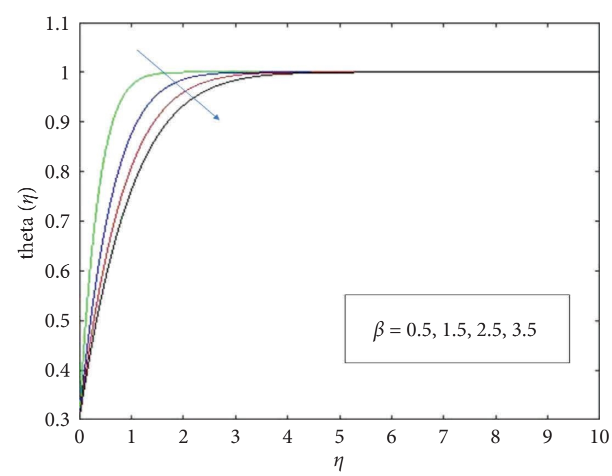

Figure 3: Effect of Casson fluid parameter on temperature profile.

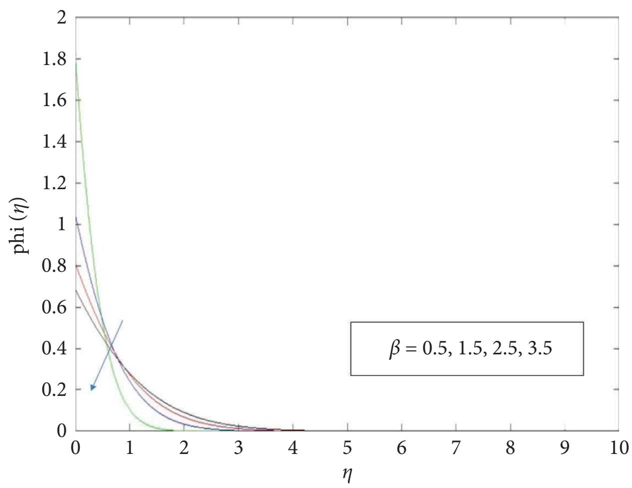

Figure 4: Concentration profile as a function of Casson fluid component.

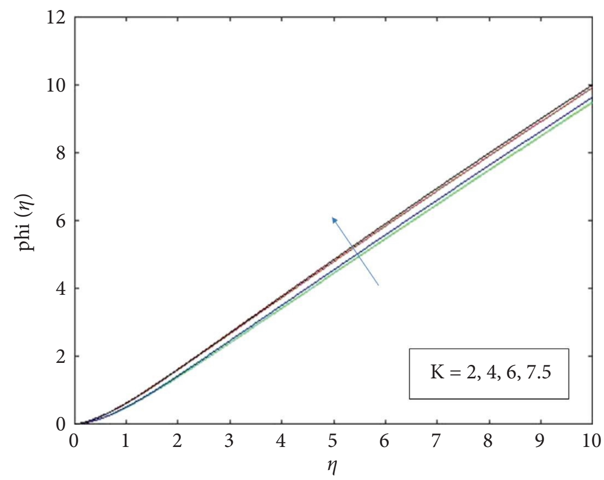

Figure 7: On the concentration profile of the chemical reaction parameter.

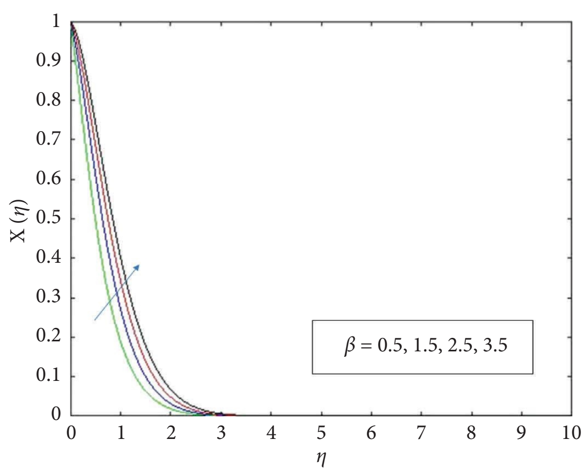

Figure 5: Bioconvection flow profile and the Casson fluid parameter.

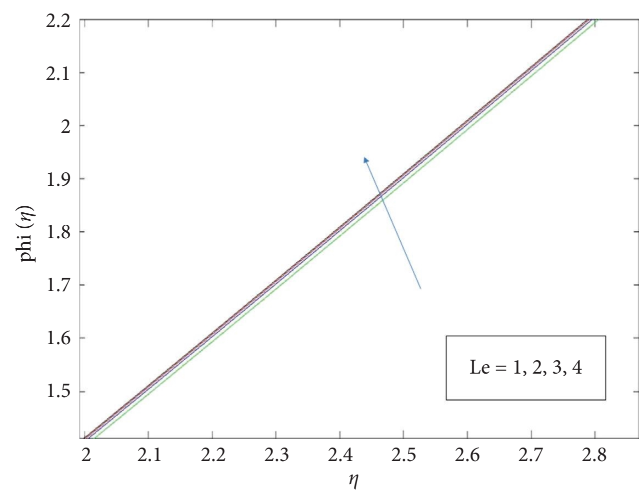

Figure 8: Concentration profile as a result of Lewis number.

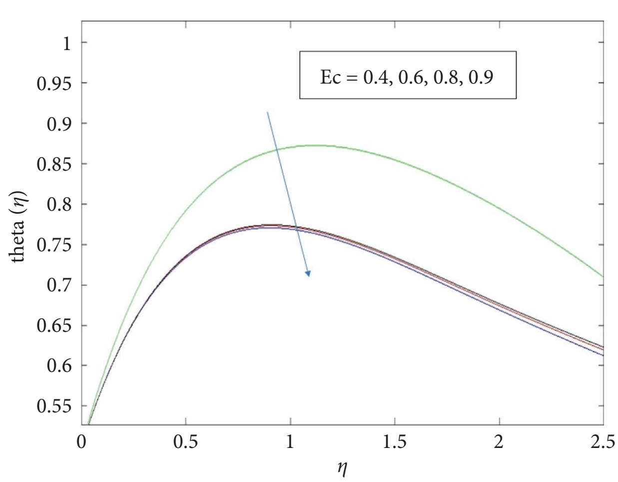

Figure 6: Temperature rise or fall depending on Eckert number.

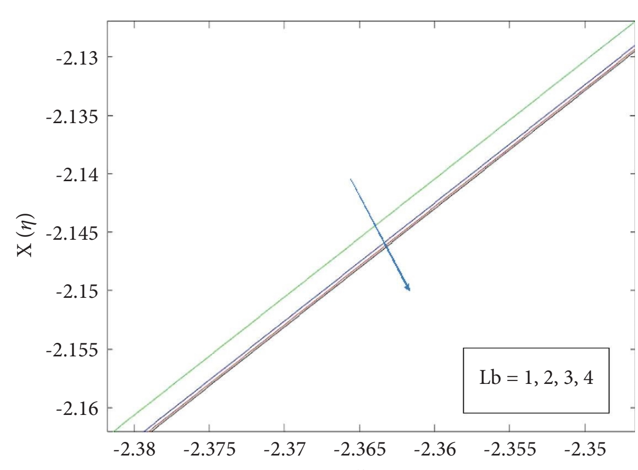

Figure 9: Effects of the bioconvection Lewis number on the bioconvection flow profiling.

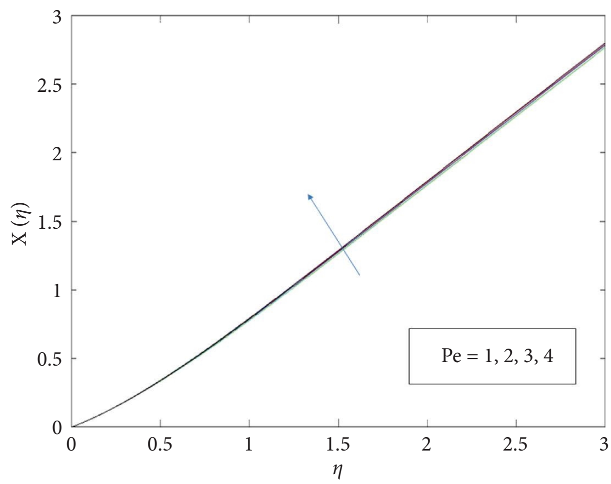

Figure 10: Bioconvection Peclet count affects flow profile.

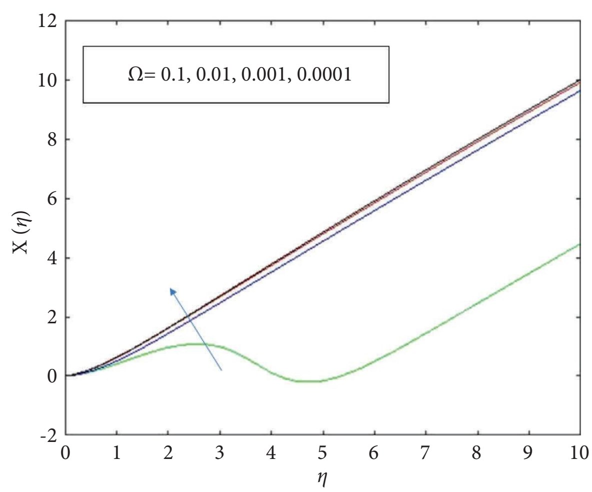

Figure 11: Bioconvection flow profile is affected by differences in the concentration of microorganisms.

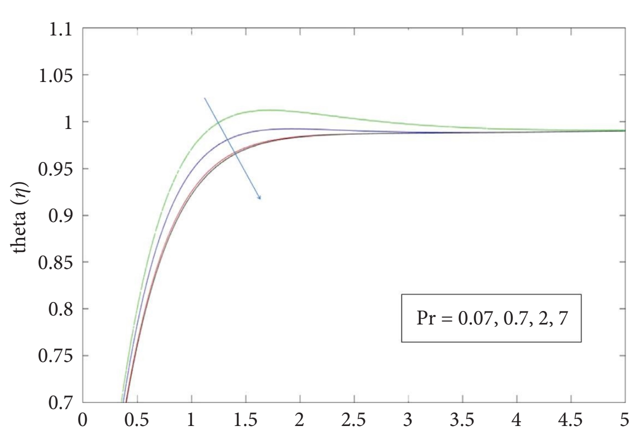

Figure 12: Prandtl number's influence on the temperature profile.

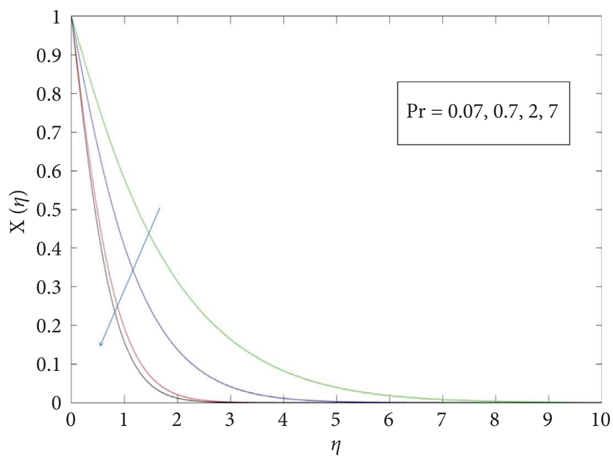

Figure 13: Prandtl number's significance on the bioconvection flow profile.

bacteria. The motile bacteria density profile degrades, and the flux of motile microorganisms on the wall increases as the bioconvection Peclet number values increase. Figure 10 elucidates the influence of P_e on bioconvection flow profile. The bioconvection flow profile amplifies with an increase in P_e. Figure 11 reflects the extent of said microorganism concentration discrepancy parameter on the bioconvection flow profile. Bioconvection flow profile is seen to improve with a decrease in Ω.

The Prandtl number is a dimensionless quantity that relates a fluid's viscosity to its thermal conductivity (Pr). Pr is the product of diffusivity and thermal conductivity. Consequently, a larger diffusivity is triggered by a higher Prandtl number, but the highest thermal diffusivity is characterized by a lower Prandtl value. Both the temperature and the thickness of the boundary layer tend to decrease due to this mechanism. Therefore, it is dependent solely on the fluid and is not dependent on the geometry of an object that is causing the issue. The Prandtl number is a trait of the fluid itself; hence, it has no bearing on the prevalence of bacteria in the flow. It is observed from Figure 12 that the temperature distribution amplifies with an increase in Prandtl number. It is found from Figure 13 that the bioconvection flow profile decreases with an increase in Prandtl number.

4. Conclusions

Over a stretching/shrinking vertical sheet, the influence of chemical reaction, temperature, and concentration in the presence of Casson nanoparticles in bioconvection flow is examined. The similarity transformation technique is being used to determine the concerns that have been resulted. From the results and discussion, it is clear that velocity profile decreases with increase in β. The effect of β and E_c decreases the temperature profile in both cases. The concentration profile increases with increasing values of β, K, and L_e. It is observed that bioconvection flow profile is enhanced with increase of β and decrease with increase of L_b, P_e, P_r, and Ω.

Data Availability

The data used to support the findings of the study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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