Hindawi
Mathematical Problems in Engineering
Volume 2022, Article ID 1707894, 9 pages
https://doi.org/10.1155/2022/1707894

Research Article

Bioconvection Flow of MHD Viscous Nanofluid in the Presence of Chemical Reaction and Activation Energy

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Received 14 October 2021; Revised 22 November 2021; Accepted 31 December 2021; Published 7 February 2022

Academic Editor: Muhammad Irfan

Enhancement of heat transfer due to stretching sheets can be appropriately controlled by the movement of the nanofluids. The concentration and settling of the nanoparticles in the viscous MHD fluid and bioconvection are addressed. In this scenario, the fluid flow occurring in the presence of a normal and uniform magnetic field, thermal radiation, and chemical reaction is taken into account. For the two-dimensional flow with heat and mass transfer, five dependent variables and three independent variables constitute the system of partial differential equations. For this purpose, similarity functions are involved to convert these equations to corresponding ODEs. Then, the Runge–Kutta method with shooting technique is used to evaluate the required findings with the utilization of MATLAB script. The fluid velocity becomes slow against the strength of the magnetic parameter. The temperature rises with the parameter of Brownian motion and thermophoresis. The bioconvection Lewis number diminishes the velocity field. Compared with the existing literature, the results show satisfactory congruences.

1. Introduction

The convoluted and quick process in massive machinery and little gadgets has produced a significant problem of thermal imbalance. Varied extraneous techniques like fins and fans are used; however, their utility is restricted because of their giant size. In 1995, the scientist Choi and Eastman [1] introduced that the nanosized particles mixed in the fluid called nanofluid have more capacity of heat transfer as compared with fluid without nanosized particles. Das et al. [2] explained the recent and future applications of fluid involving nanosized particles. Khan et al. [3] using the shooting method analyzed flow features of Williamson nanofluid influenced by variable viscosity depending on temperature and Lorentz force past an inclined nonlinear extending surface. Koo and Kleinstreuer [4] described influences of convection, conduction, viscous dissipation, and thermal transportation on nanofluid flow in a microchannel. Sui et al. [5] introduced the CattaneoeChristov model with double diffusion to analyze the influence of slip velocity, Brownian motion, and variable viscosity on the transportation of an upper convected Maxwell nanofluid through stretching sheet. Imran et al. [6] determined an unsteady stream of Maxwell fluid through an accelerated exponentially vertical surface with influences of radiation, Newtonian heating, MHD, and slip condition taken into account. Khan et al. [7] investigated the flow of micropolar base nanofluid through stretching sheet with thermal radiation and magnetic dipole. Sheikholeslami and Rokni [8] scrutinized magnetic field impacts on the thermal transport rate in a nanofluid. Seyyedi et al. [9] analyzed the entropy generation for Cu-water nanofluid having a semi-annulus porous wavy cavity in the presence of a magnetic field. Molana et al. [10] discussed the characteristics of heat transfer and natural convection of nanofluid past a porous cavity with a constant inclined magnetic field. Dogonchi et al. [11] explained the characteristics of natural convection and magnetic field on nanofluid flow through porous medium with effects of Hartmann number, Rayleigh number, and Darcy number taken into account. Shaw et al. [12] scrutinized the impact of nonlinear thermal and entropy generation on Casson nanofluid flow with rotating disk and also described the brain function. Chamkha et al. [13] explained MHD nanofluid flow through cavity using the control-volume-based finite element method with effects of natural convection, thermal radiation, and shape factor of nanoparticles taken into account. Dogonchi et al. [14] numerically introduced the importance of the Cattaneo–Christov theory of heat conduction through triangular semicircular heater with viscosity dependent on the magnetic field. Seyyedi et al. [15] described the entropy generation and natural convection heat transfer of Cu-water nanoliquid through the hexagonal cavity. Sadeghi et al. [16] analyzed the thermal behavior of magnetic buoyancy-driven flow in ferrofluid-filled wavy enclosure furnished with two circular cylinders.

Stretching sheets because of their wide applications like plastic film, metal drawing and spinning, glass fiber, paper processing, and heat moving have become an important topic in the past decades. Recently, some researchers investigated the magnetohydrodynamic flow with the different effects such as viscous dissipation and chemical reaction using stretching sheet (see Ismail et al. [17], Rajput et al. [18], Swain et al. [19], Reddy et al. [20], Jat and Chand [21], Sajid and Hayat [22], Ishak [23], Abd El-Aziz [24], Makinde [25], and Goud et al. [26]).

Bioconvection described the phenomena in which living microorganisms denser than water swim upward in suspensions. These microorganisms pile up in the layer of the upper surface and lower surface becomes less dense. The microorganisims fall down due to unstability of density distribution. Bioconvection has applications in biological systems and biotechnology such as purifying cultures, enzyme biosensors, and separating dead and living cells [27]. Raees et al. [28] examined the unsteady stream of bioconvection mixed nanofluid having gyrostatic motile microorganisms through a horizontal channel. Siddiqa et al. [29] numerically studied the bioconvection flow of nanofluid having mass and thermal transportation along with gyrotactic microorganisms through a curved vertical cone. Abbasi et al. [30] introduced the bioconvection stream of viscoelastic nanofluid because of gyrotactic microorganisms past a rotating extending disk having zero mass flux and convective boundary condition and also described the relatable parameters influences on velocity, temperature, local density, Sherwood number, and Nusselt number in detail. Chu et al. [31] analyzed the stream of bioconvection MHD fluid through extending sheet with the significance of motile microorganisms, activation energy, thermophoresis diffusion, Brownian motion, and chemical reaction taken into account. Henda et al. [32] examined the magnetized bioconvection flow of fluid past an extending cylinder with thermal radiation, activation energy, and heat source. Khan et al. [33] scrutinized bioconvection stream of viscous nanofluid through (cone, wedge, and plate) multiple geometries with effects of heat flux, cross-diffusion, and Cattaneo–Christov.

Inspired by the above literature survey, our interest pertains to extending the results of Goud et al. [26] to investigate a more general problem, including bioconvection of nanofluid transportation with the effects of chemical reaction and radiation to avoid probable settling of nanoentities. The connotation of such meaningful attributes can be a useful extension, and the results can be utilized for desired effective thermal transportation in the heat exchanger of various technological processes.

2. Problem Formulation

Here, we considered steady incompressible magnetohydrodynamic nanofluid flow through exponentially stretching sheet along the x-axis and y-axis taken to be normal with velocity $\widetilde{U}_w = a_0 e^{x/l}$ as shown in Figure 1. A magnetic field is applied to the flow region and acts in the y-direction. A mild diffusion of microorganisms and nanoparticles is set in the fluid. Thermal radiation is considered, and bioconvection takes place because of microorganisms' movement. The fluid velocity for two-dimensional flow is $\widetilde{u}, \widetilde{v}$.

Under the above conditions, the governing equations are as follows [20, 26]. Continuity equation is as follows:

$$\widetilde{u}_x + \widetilde{v}_y = 0, \tag{1}$$

momentum equation is as follows:

$$\widetilde{u}\widetilde{u}_x + \widetilde{v}\widetilde{u}_y = \nu\widetilde{u}_{yy} - \frac{\sigma}{\rho}\left(B_0^2\widetilde{u}\right) + \frac{1}{\rho}\left[g\beta\rho\left(1-\widetilde{C}_\infty\right)\left(\widetilde{T}-\widetilde{T}_\infty\right) - g\left(\rho_p-\rho_f\right)\left(\widetilde{C}-\widetilde{C}_\infty\right) - g\gamma\left(\rho_m-\rho_f\right)\left(\widetilde{N}-\widetilde{N}_\infty\right)\right], \tag{2}$$

energy equation is as follows:

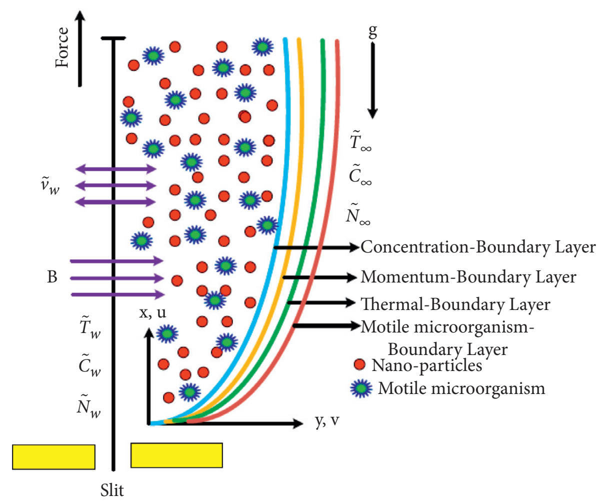

Figure 1: Geometry of the problem.

$$\tilde{u}\tilde{T}_x + \tilde{v}\tilde{T}_y = \alpha\tilde{T}_{yy} - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial y} + \tau\left(D_B\tilde{T}_y\tilde{C}_y + \frac{D_T}{\tilde{T}_\infty}\left(\tilde{T}_y\right)^2\right), \quad (3)$$

concentration equation is as follows:

$$\tilde{u}\tilde{C}_x + \tilde{v}\tilde{C}_y = D\tilde{C}_{yy} - K_r\left(\tilde{C} - \tilde{C}_\infty\right) - K_r^2\left(\tilde{C} - \tilde{C}_\infty\right)\left(\frac{\tilde{T}}{\tilde{T}_\infty}\right)^n \exp\left(\frac{-Ea}{k\tilde{T}}\right) + \frac{D_T}{\tilde{T}_\infty}\tilde{T}_{yy}, \quad (4)$$

bioconvection equation is as follows:

$$\tilde{u}\tilde{N}_x + \tilde{v}\tilde{N}_y + dW_c\frac{\partial}{\partial y}\left(\frac{\tilde{N}}{\Delta\tilde{C}}\tilde{C}_y\right) = \tilde{N}_{yy}D_n, \quad (5)$$

with constraints

$$\begin{aligned} &\tilde{u} = \tilde{U}_w,\ \tilde{v} = 0,\ \tilde{T} = \tilde{T}_w,\ \tilde{C} = \tilde{C}_w,\ \tilde{N} = \tilde{N}_w\ at\ y \longrightarrow 0,\\ &\tilde{u} \longrightarrow 0,\ \tilde{T} \longrightarrow \tilde{T}_\infty,\ \tilde{C} \longrightarrow \tilde{C}_\infty,\ \tilde{N} \longrightarrow \tilde{N}_\infty\ as\ y \longrightarrow \infty. \end{aligned} \quad (6)$$

Now, introducing

$$\tilde{U}_w = a_0e^{x/l},\ \tilde{T}_w = \tilde{T}_\infty + \tilde{T}_0e^{x/2l},\ \tilde{C}_w = \tilde{C}_\infty + \tilde{C}_0e^{x/2l},\ \tilde{N}_w = \tilde{N}_\infty + \tilde{N}_0e^{x/2l}, \quad (7)$$

under the Rosseland approximation q_r [26], equation (3) can be written as

$$\tilde{u}\tilde{T}_x + \tilde{v}\tilde{T}_y = \tilde{T}_{yy}\left(\alpha + \frac{16\sigma^* T_\infty^3}{\rho C_p 3k_1}\right) + \tau\left(D_B \tilde{T}_y \tilde{C}_y + \frac{D_T}{\tilde{T}_\infty}\left(\tilde{T}_y\right)^2\right). \tag{8}$$

Introducing similarity transformation,

$$\eta = y\sqrt{\frac{a_0}{2\nu\ell}}e^{x/2l},\ \tilde{u} = a_0 e^{x/l} f'(\eta),\ \tilde{v} = -\sqrt{\frac{a_0\nu}{2\ell}}e^{x/2l}\left[f(\eta) + \eta f'(\eta)\right],$$
$$\psi = \sqrt{2\nu L a_0} f(\eta) e^{x/2l}, \tilde{T} = \tilde{T}_\infty + \tilde{T}_0 e^{x/2l},\ \tilde{C} = \tilde{C}_\infty + \tilde{C}_0 e^{x/2l},\ \tilde{N} = \tilde{N}_\infty + \tilde{N}_0 e^{x/2l}. \tag{9}$$

In view of the above appropriate relations, equation (1) is satisfied identically and equations (2)–(5), respectively, become

$$f''' - Mf' - 2f'^2 + ff'' + \lambda(\theta - Nr\phi - Rb\chi) = 0, \tag{10}$$

$$\left(1 + \frac{4}{3}K\right)\theta'' + \Pr f\theta' - \Pr\theta f' + \theta'(Nb\phi' + Nt\theta') = 0, \tag{11}$$

$$\phi'' + \left[f\phi' - Cr\phi - \phi f' - \sigma_m\phi(1+\delta\theta)^n \exp\left(\frac{-E}{1+\delta\theta}\right)\right]Sc + \frac{Nt}{Nb}\theta'' = 0, \tag{12}$$

$$\chi''(\xi) + Lb\Pr f(\xi)\chi'(\xi) - Lb\Pr f'(\xi)\chi(\xi) - Pe\left(\sigma_1\phi''(\xi) + \chi(\xi)\phi''(\xi) + \chi'(\xi)\phi'(\xi)\right) = 0, \tag{13}$$

and the constraints reduce to

$$f'(0) = 1,\ f(0) = 0,\ \phi(0) = 1,\ \theta(0) = 1,\ \chi(0) = 1,\ at\ \eta = 0, \tag{14}$$

$$f'(\infty) \longrightarrow 0,\ \phi(\infty) \longrightarrow 0,\ \theta(\infty) \longrightarrow 0,\ \chi(\infty) \longrightarrow 0.\ as\,\eta \longrightarrow \infty. \tag{15}$$

The associated parameters are

$$M = \frac{2\sigma B_0^2\ell}{\rho\tilde{U}_w},$$
$$\Pr = \frac{\nu}{\alpha},$$
$$\lambda = \frac{(1 - C_\infty)\beta g(T_w - T_\infty)2\ell}{\tilde{U}_w^2},$$
$$Nr = \frac{\left(\rho_p - \rho_f\right)(C_w - C_\infty)}{\beta(1 - C_\infty)\rho(T_w - T_\infty)},$$
$$Rb = \frac{\left(\rho_m - \rho_f\right)\gamma(N_w - N_\infty)}{\rho(1 - C_\infty)\beta(T_w - T_\infty)},$$
$$Nt = \frac{\tau D_T(T_w - T_\infty)}{\nu T_\infty},$$
$$Nb = \frac{\tau D_B(C_w - C_\infty)}{\nu},$$
$$\sigma_m = \frac{2K_r^2\ell}{\tilde{U}_w},$$
$$\delta = \frac{(T_w - T_\infty)}{T_\infty},$$
$$K = \frac{4\sigma^* T_\infty^3}{k^* K},$$
$$\sigma_1 = \frac{N_\infty}{N_w - N_\infty},$$

Table 1: Comparison of $\theta'(0)$ with changed values of K, M, and Pr.

K	M	Pr	Ishak [23]	Goud et al. [26]	Bidin and Nazar [34]	Our results
		1.0	0.954 8	0.954 784	0.954 7	0.954 810 6
		2.0	1.471 5	1.471 462	1.471 4	1.471 454 0
	0	3.0	1.869 1	1.869 073	1.869 1	1.869 068 8
0.0		5.0	2.500 1	2.500 111		2.500 128 0
		10.0	3.660 4	3.660 346		3.660 369 3
	1.0	1.0	0.861 1	0.861 097		0.861 508 6
1.0	0.0		0.531 2	0.531 17	0	0.531 311 2
	1.0		0.450 5	0.450 687	0	0.450 695 5

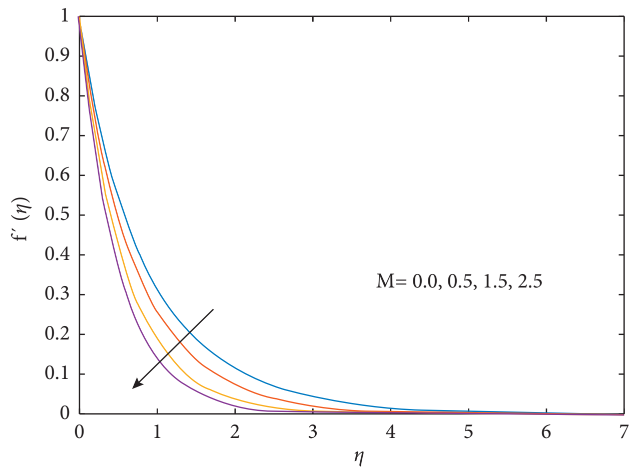

Figure 2: Influences of M on f'.

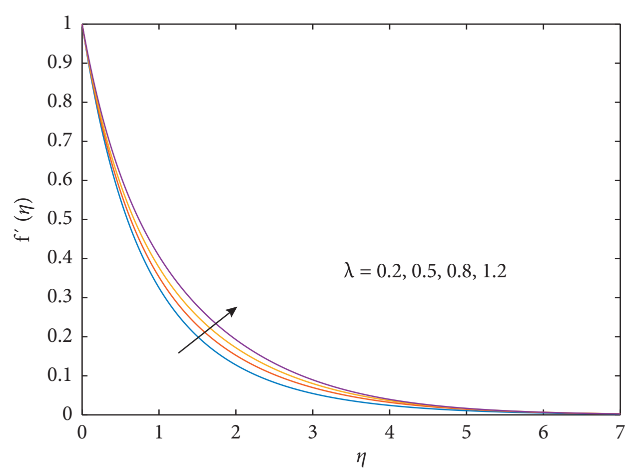

Figure 3: Influences of λ on f'.

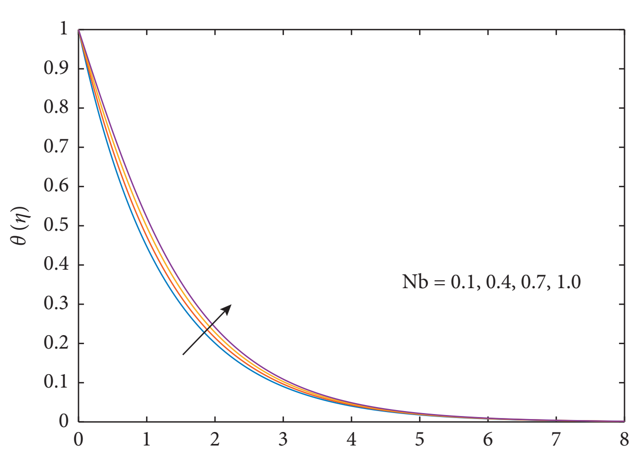

Figure 4: Influences of Nb on θ.

$$E = \frac{Ea}{kT_\infty},$$
$$Sc = \frac{\nu}{D},$$
$$Lb = \frac{\alpha}{D_n}, \tag{16}$$
$$Pe = \frac{dW_c}{D_n},$$
$$Cr = \frac{2\ell K_r}{\widetilde{U}_w},$$

where M is the magnetic field parameter, Pr is the Prandtl number, λ is the mixed convection parameter, Nr is the buoyancy ratio number, Rb is the bioconvection Rayleigh number, Nt is the thermopherosis diffusion factor, Nb is the Brownian factor, σ_m denotes the dimensionless reaction rate, δ is used as the temperature distinction parameter, K is the radiation parameter, σ_1 is the bioconvective difference parameter, E means the nondimensional energy activation, Sc is the Schmidt number, Lb is the bioconvection Lewis number, Pe is the peclet number, and Cr is the chemical reaction parameter.

The wall shear stress, thermal flux, and mass flux, respectively, are given as

$$\tau_w - \mu\left(\frac{\partial \tilde{u}}{\partial y}\right)_{y=0} = 0, q_w + k\left(\frac{\partial \widetilde{T}}{\partial y}\right)_{y=0} = 0, j_w + D\left(\frac{\partial \tilde{c}}{\partial y}\right)_{y=0} = 0. \tag{17}$$

C_f (skin friction), Nu_x (Nusselt number), and Sh_x (sherwood number) in dimensionless form are

$$C_f = \frac{f''(0)}{\sqrt{2\mathrm{Re}_x}}, \quad Nu_x = -\left(\sqrt{\mathrm{Re}_x}\right)\theta'(0), \quad Sh_x \mathrm{Re}^{-1/2} = -\phi'(0). \tag{18}$$

3. Results and Discussion

Physical meanings of the final nondimensional formulation of time-independent MHD flow of nanofluid due to stretch of an exponential sheet in the presence of chemical reaction along the boundary constraints are solved numerically. Table 1 contains results for $-\theta'(0)$ (Nusselt number). Comparison of the results indicates acceptable agreement to validate this numeric procedure. In Figure 2, the velocity of the flow seems to be reduced significantly when magnetic parameter M $(0.0 \leq M \leq 2.5)$ is increased because high values of magnetic field parameter improve the contradictory force known as Lorentz force. The improvement of mixed convection parameter λ causes to boost the flow velocity $f'(\eta)$ as shown in Figure 3. From Figures 4 and 5, significant rising behavior of $\theta(\eta)$ is noticed with an enhanced value of Brownian motion parameter Nb and thermophoresis parameter Nt. The fast random motion of nanoparticles characterized by larger Nb is responsible for enhanced heat transfer to raise $\theta(\eta)$. Similarly, the higher Nt means a greater thermophoretic effect which moves the nanoparticles hotter regime to the colder one and increases the thermal distribution. The similarly larger value of E provides strength to $\phi(\eta)$ as depicted in Figure 6. Figure 7 displays the decrement in $\phi(\eta)$ due to the larger value of chemical reaction, and the chemical reaction becomes faster to recede nanoparticles concentration. The bioconvection Rayleigh Rb and parameter are responsible for given direct increment to $\chi(\eta)$ as demonstrated in Figure 8.

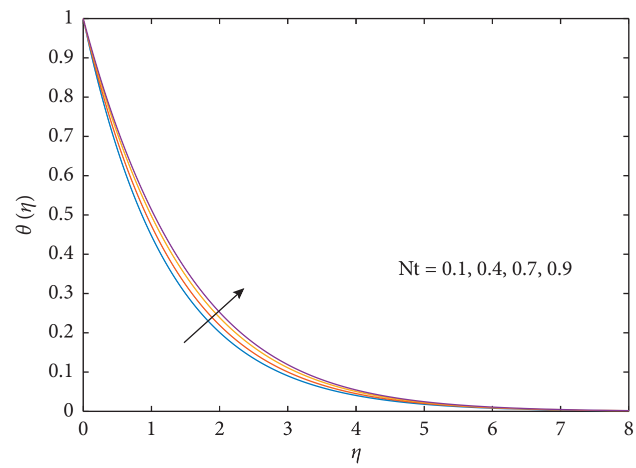

Figure 5: Influence of Nt on ϕ.

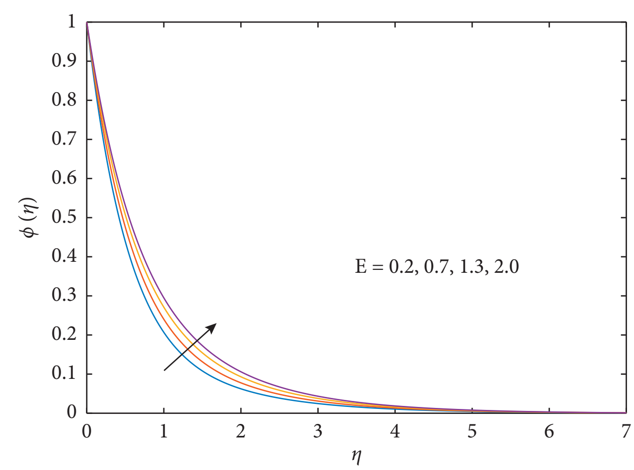

Figure 6: Influences of E on ϕ.

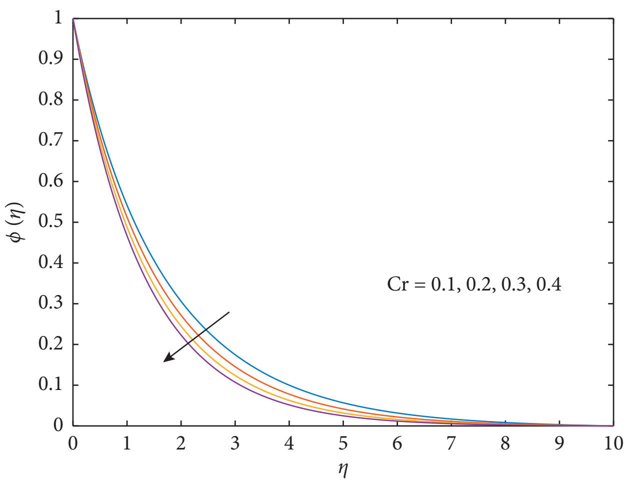

Figure 7: Influences of Cr on ϕ.

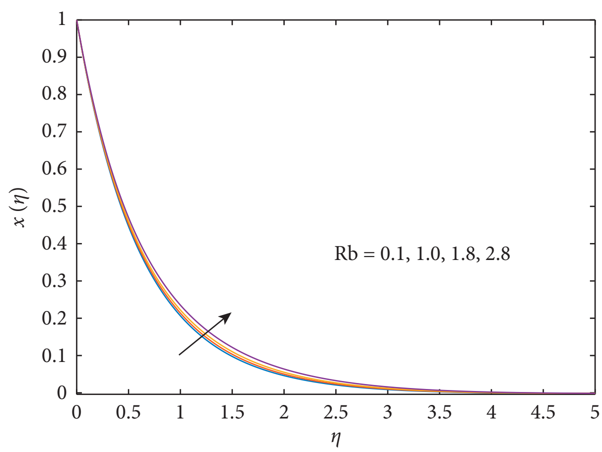

Figure 8: Influences of Rb on χ.

4. Conclusions

Theoretical and numeric analysis for magnetohydrodynamic of nanofluid owing to sudden stretched in an exponential sheet has been made in this communication. Effects of the emerging parameters are enumerated on the physical field, namely, velocity, temperature, and microorganisms distribution. Significant outcomes are summarized as follows:

(i) The velocity reduces with M and boosts with λ

(ii) The conclusion of nanoparticles characterized by parameters Nb and Nt shows an increment in the temperature profile

(iii) Concentration recurses with Cr and is enhanced with E

(iv) Bioconvection parameter is increased with Rb

Nomenclature

B_0: Coefficient of magnetic field
C: Concentration
T: Temperature
N: Concentration of microorganisms
Nt: Thermopherosis parameter
(x, y): Cartesian coordinates
Cr: Chemical reaction parameter
(u, v): Velocity components along (x, y)-axes
τ: Heat capacity ratio
ξ: Similarity variable
D_T: Thermophoretic diffusion coefficient
ϕ: Dimensionless concentration
q_r: Radiative heat flux
ρ: Density
K_r^2: Chemical reaction rate constant
μ: Dynamic viscosity of the fluid
K_r: Rate of chemical reaction
σ: Electrical conductivity
D_B: Brownian diffusivity
ψ: Stream function
K: Radiation parameter
δ: Temperature distinction parameter
Sc: Schmidt number
λ: Mixed convection parameter
U_w: Stretching velocity
ν: Kinematic viscosity
Pr: Prandtl number
θ: Dimensionless temperature
Pe: Peclet number
χ: Dimensionless microorganism factor
M: Magnetic parameter
ρ_f: Density of nanofluid
Nr: Buoyancy ratio number
ρ_m: Density of microorganisms particle
Rb: Bioconvection Rayleigh number
ρ_p: Density of nanoparticles
Nb: Brownian motion parameter
κ: Thermal conductivity
n: Fitted rate constant parameter
α: Thermal diffusivity
g: Gravity
β: Volumetric coefficient of thermal expansion
E: Nondimensional activation energy
γ: Average volume of microorganism
Lb: Bioconvection Lewis number
Sh_x: Local Sherwood Number
W_c: Maximum cell swimming speed
σ_m: Dimensionless reaction rate
D_n: Microorganisms diffusion coefficient
σ_1: Bioconvection diffrrence parameter
σ^*: Stefan Boltzman constant
Nu_x: Local Nusselt number
C_f: Local skin friction number
Re_x: Local Reynolds number.

Data Availability

The data used to support this study are included within this article.

Conflicts of Interest

The authors declare that they have no known personal relationships or conflicts of interest that could have appeared to the work reported in this work.

Authors' Contributions

All authors contributed equally and significantly in writing this paper. All authors read and approved the manuscript.

Acknowledgments

This research was supported by Taif University Researchers Supporting Project Number TURSP-2020/96, Taif University, Taif, Saudi Arabia.

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