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Bioconvection Due to Gyrotactic Microorganisms in a Porous Medium with Chemical Reaction, Heat Generation and Slip Velocity

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Abstract

Bioconvection has gained popularity among researchers because of its wide-ranging applications in industry and manufacturing. This study aims to investigate bioconvection driven by motile gyrotactic microorganisms with chemical reactions and internal heat generation past a permeable slip vertical plate embedded in a porous medium. The system of governing partial differential equations is transformed into a system of ordinary differential equations using similarity transformations. These equations are then solved using MATLAB's bvp5c solver. The Nusselt number, Sherwood number, and the density of motile microorganisms are calculated and presented in tabular form. The findings indicate that as the inverse Darcy number increases, the velocity profiles decrease. The slip parameter decreases the velocity profiles near the surface. Additionally, the effect of chemical reactions demonstrates that the mass transfer rate is enhanced by a high destructive chemical rate, resulting in a drop in concentration and gyrotactic microorganisms across the boundary layer region. The temperature profiles increase with higher values of the heat generation parameter. In bioconvection systems, chemical reactions influence microbial behavior and metabolism, porous media facilitate nutrient transport, and heat generation can be applied to wastewater treatment and biofuel production.

Keywords: Porous medium; slip velocity; heat generation; chemical reaction; bioconvection

1 Introduction

Bioconvection due to gyrotactic microorganisms in a porous medium is an area of interest in the fields of fluid dynamics and biophysics. It has relevance in various scientific and engineering applications. Bioconvection driven by gyrotactic microorganisms refers to a specific type of bioconvection where the organized movement of microorganisms is influenced by their gyrotactic behavior. This natural process is significant in microbiological systems, impacting biotechnology and biosensors by improving mixing and mass transfer. According to [1], bioconvection helps promote the rate of mass transfer and microscale mixing, particularly in micro volumes, and improves the fluid's stability in the flow. Gyrotactic microorganisms have a distinct movement pattern due to their response to the vorticity or shear rate of the ambient fluid, which sets them apart from chemotactic and geotactic microorganisms [2]. Bioconvection is important and plays a crucial role in environmental processes such as nutrient transport, microbial ecology, and biogeochemical cycling. Motile microorganisms, key players in bioconvection, contribute to the macroscopic movement of fluids resulting from density gradients formed by their collective floating.

According to [3], motile microorganisms are self-propelled, which increases the density of the base fluid as they swim in a particular direction in response to stimuli like gravity, light, or chemical attraction. Additionally, motile microorganisms are used to enhance the mixability of particles and fluid because they are responsible for the biological transmission process. [4] examined magnetohydrodynamics (MHD) fluids, including motile microorganisms, along with conditions of viscosity loss and convection. [5] investigated the activation in the bioconvection flow of a cross liquid subject to gyrotactic microorganisms. Furthermore, [6] deals with the analysis of bioconvection caused by the movement of gyrotactic microorganisms under thermophoretic force and Brownian motion.

Meanwhile, porous media can also contribute to reducing flow instabilities in bioconvection, which is important for understanding and controlling the dynamics of bioconvection in fluid systems. Applications of porous media include heat exchangers, porous burners, solar collectors, and porous blades. Flows through porous media are of great interest to petroleum engineers and geophysical fluid dynamists. The principle of using porous media models to reduce flow instabilities in bioconvection is discussed by [7]. [8] investigated the bioconvection of fluid containing gyrotactic microorganisms over a stretching surface implanted in a porous medium. Additionally, [9] performed an analytical study on gyrotactic microorganisms in porous media. The primary goal was to control the thermal efficiency of the medium and investigate bioconvection. They discovered that gyrotactic mechanism of microbes is not influenced by the porous medium having high porosity or much smaller permeability.

Chemical reactions play an essential role in bioconvection, impacting the behaviour of microorganisms and the transport of heat and mass in the system. A chemical reaction occurs when two or more chemicals interact, producing one or more new chemical compounds. These reactions can influence the behaviour of microorganisms involved in bioconvection. The presence of specific chemicals or variations in chemical concentrations can alter the swimming patterns, motility, or aggregation of these microorganisms. Researchers have numerically addressed the mixed convective flow of magneto-nanofluid under the influences of chemical reactions and activation energy [10]. The effects of chemical reactions on bioconvective flow in a porous cavity containing oxytactic microorganisms have been examined by [11]. [12] analysed the stream of bioconvection MHD fluid through an extending sheet, considering factors such as motile microorganisms, activation energy, thermophoresis diffusion, Brownian motion, and chemical reactions. Furthermore, [13] explained how the parameters of chemical reactions and porous medium affect the flow of microorganisms in a fluid flow through a porous medium. Additionally, various researchers have investigated bioconvection in the presence of microorganism flow along vertical surfaces with heat generation.

Heat generation is an important factor that can affect the behavior of fluids and microorganisms in bioconvection. It refers to the production of heat through chemical reactions or other processes. In the context of bioconvection, heat generation can impact the temperature and thermal energy of the fluid, which in turn affects the behavior of microorganisms and the convective flow. In a study by [14], the unsteady MHD stagnation point flow of bio nanofluid with internal heat generation in a permeable medium was analyzed, considering thermal radiation and chemical reaction over a stretching and shrinking sheet. Another study [15] investigated the effects of double-diffusivity heat generation on the bioconvection process on a vertical porous surface with variable fluid properties. They found that heat generation has a significant impact on the bioconvective flow, mass, and heat transfer, including motile microorganisms on a vertical surface saturated with porous media.

Moreover, slip velocity at the fluid-solid interface can enhance mass and momentum transport. The slip condition has a significant effect on bioconvection in fields such as biotechnology, medicine, and environmental science. Slip velocity refers to the relative velocity between the fluid and the microorganisms, particularly gyrotactic microorganisms, which can influence the collective movement of the fluid. It is an important parameter that affects the velocity profiles, flow dynamics, and overall behavior of the bioconvection flow. In a study by [16], unsteady MHD convective heat and mass transfer past a vertical permeable plate were studied under the effect of slip boundary conditions, along with thermal radiation and chemical reaction. [17] explored the bioconvection fluid flow across a permeable surface in the presence of gyrotactic microorganisms. The study found that slip velocity plays a significant role in modulating microorganism concentration in the bioconvection flow, thereby affecting the distribution and behavior of microorganisms as well as the overall convective flow.

Based on the discussion above, it is evident that the existing literature does not sufficiently explore bioconvection involving gyrotactic microorganisms, chemical reactions, heat generation, and slip velocity together. In the past, no researchers have considered the combined effects of heat generation, slip velocity, porous medium, and chemical reactions. This paper is inspired by [3] and [18]. Therefore, the objective of this study is to analyze the bioconvection of gyrotactic microorganisms past a permeable vertical plate embedded in a porous medium with chemical reaction, heat generation, and slip velocity. The outcomes obtained by varying the relevant parameters are presented and discussed using tables and graphs. These findings are significant for industries such as pharmaceuticals, biological polymer synthesis, and environmentally friendly processes. In bioconvection systems, chemical reactions influence microbial behavior and metabolism, porous media facilitate nutrient transport, and heat generation can be applied to wastewater treatment and biofuel production.

2 Mathematical Formulation

A two-dimensional steady flow of an electrically containing gyrotactic microorganisms past a permeable vertical plate embedded in a porous medium is considered. The ambient temperature, the mass concentration and the density of motile microorganisms are denoted by T_∞, C_∞ and n_∞ respectively. The steady bioconvection as shown in Figure 1, with surface slip embedded in a porous medium in presence of a transverse magnetic field B_O is considered. The magnetic Reynolds number of the flow is taken to be small enough so that induced magnetic field is assumed to be negligible in comparison to the applied magnetic field.

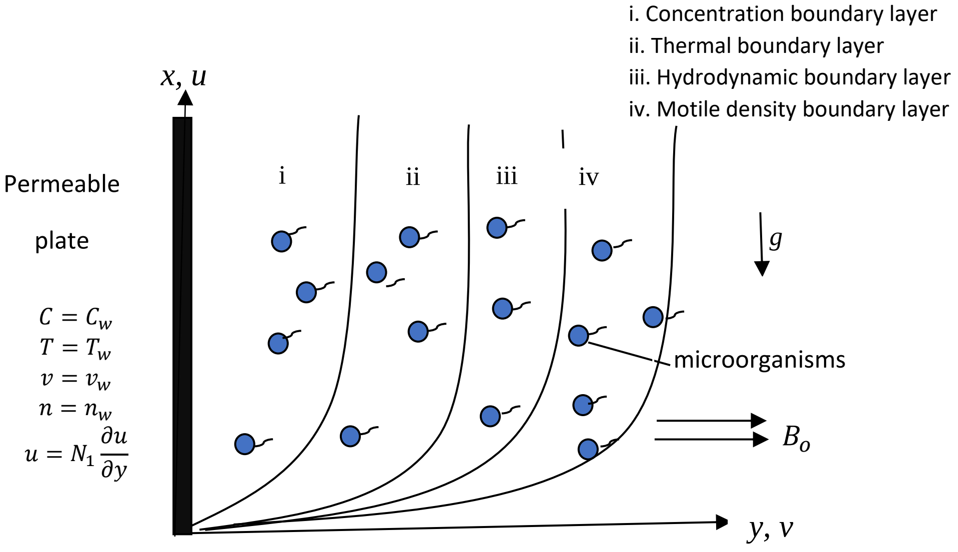

Figure 1 Flow configuration

Under the above assumptions along with the Oberbeck-Boussinesq approximation, the governing equation of continuity, momentum, energy, and microorganisms can be written as [18], [3] and [13].

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

$$\begin{gathered}\frac{\partial p}{\partial x} = \mu \frac{\partial^2 u}{\partial y^2} - \sigma B_o^2 u - \rho_f \left(u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} \right) - \frac{\epsilon \mu}{k} u + g[(1 - \emptyset_\infty)\rho_{f\infty}\beta g (T - T_\infty) \\ - \left(\rho_p - \rho_{f\infty}\right)(C - C_\infty) - ng\gamma\left(\rho_{m\infty} - \rho_{f\infty}\right)]\end{gathered} \tag{2}$$

$$u \frac{\partial T}{\partial x} + \frac{\partial T}{\partial y} = \alpha \frac{\partial^2 T}{\partial y^2} + \tau \left\{ D_B \frac{\partial C}{\partial y} \frac{\partial T}{\partial y} + \frac{D_T}{T_\infty} \left(\frac{\partial T}{\partial y} \right)^2 \right\} + \frac{\mu \alpha}{k} \left(\frac{\partial u}{\partial y} \right)^2 + \frac{\alpha \sigma B_o^2 u^2}{k} + \frac{Q_o}{(\rho C)_f} (T - T_\infty) \tag{3}$$

$$u \frac{\partial C}{\partial x} + v \frac{\partial C}{\partial y} = D_B \frac{\partial^2 C}{\partial y^2} + \frac{D_T}{T_\infty} \frac{\partial^2 T}{\partial y^2} - K_r (C - C_\infty) \tag{4}$$

$$u\frac{\partial n}{\partial x}+v\frac{\partial n}{\partial y}+\frac{bW_C}{(C_W-C_\infty)}\left[\frac{\partial}{\partial y}\left(n\frac{\partial C}{\partial y}\right)\right]=D_m\frac{\partial^2 n}{\partial y^2} \tag{5}$$

The appropriate physical boundary condition for the problem is given by [3] and [18]

$$u=N_1\frac{\partial u}{\partial y}, v=v_w, C=C_{w,}T=T_w, n=n_w\; at\; y=0 \tag{6a}$$

$$u\longrightarrow 0, v\longrightarrow 0. C\longrightarrow C_\infty. T\rightarrow T_\infty, n\rightarrow n_\infty\; as\; y\rightarrow\infty \tag{6b}$$

where *u, v* are the velocity components along the x and *y*-axis respectively. N_1 is the Navier slip coefficient. T is temperature, T_w is the constant wall temperature. C is the concentration, C_w is the mass concentration at the wall. n is the concentration of microorganisms, n_w is the density of motile microorganisms at the wall. ε is the porosity of the porous medium, k is the permeability of the porous medium, μ is the viscosity of the suspension of microorganisms, σ is the electrical conductivity, β is the volumetric thermal expansion coefficients of base fluid, γ is the average volume of a microorganisms, α is the thermal diffusivity, κ is the thermal conductivity, $\tau=\frac{(\rho c)_p}{(\rho c)_f}$ is the ratio of the effective heat capacity and the base fluid, ρ_f is the density of the base fluid, ρ_p is the nanoparticle density, ρ_m is the density of microorganisms, D_B is the Brownian diffusion coefficient, D_T is the thermophoretic diffusion coefficient, D_m is the diffusivity of microorganisms, b is the chemotaxis constant and W_c is the maximum cell swimming speed, K_r is the constant rate of chemical reaction between the base fluid and particle where $K_r>0$ for destructive reaction and the subscript ∞ denotes the corresponding values at far field.

To solve the governing equations (1) to (5) with boundary condition (6), we first convert the partial differential equations (PDEs) into ordinary differential equations (ODEs). To do this, the following dimensionless variables, as adopted by [18], [3] and [19]

$$\eta=\frac{y}{x}Ra_x^{\frac{1}{4}}, \psi=\alpha Ra_x^{\frac{1}{4}}f(\eta), \qquad \theta(\eta)=\frac{T-T_\infty}{T_w-T_\infty},$$
$$\phi(\eta)=\frac{C-C_\infty}{C_w-C_\infty}, \chi(\eta)=\frac{n-n_\infty}{n_w-n_\infty}, Ra_x=\frac{(1-\phi_\infty)\beta g\Delta T_f}{\alpha v}x^3, \tag{7}$$

where Ra_x is the reference local Rayleigh number. By substituting equation (7) into equations (1) to (5), the continuity equation (1) is automatically satisfied and Equations (2) to (5) becomes

$$f'''+\frac{3}{4Pr}ff''-\frac{1}{2Pr}f'^2+\theta-Nr\phi-Rb\chi-Da^{-1}f'=0, \tag{8}$$

$$\theta''+\frac{3}{4}f\theta'+Nb\emptyset'\theta'+Nt\theta'^2+EcPr(f''^2+Mf'^2)+PrQ\theta=0, \tag{9}$$

$$\phi''+\frac{3}{4}Lef\phi'+\frac{Nt}{Nb}\theta''-Kr\phi=0, \tag{10}$$

$$\chi''+\frac{3}{4}Lbf\chi'-Pe[\phi'\chi'+\phi''(\sigma+\chi)]=0. \tag{11}$$

The boundary condition 6 has converted to

$$f'(0)=f_w, f'(0)=\lambda f''(0), \theta(0)=1, \phi(0)=1, \tag{12a}$$

$$\chi(0)=1, f'(\infty)=0, \theta(\infty)=0, \chi(\infty)=0. \tag{12b}$$

Where f' is the dimensionless velocity, η is the similarity variable, θ is the dimensionless temperature, ϕ is the dimensionless concentration and χ is the dimensionless density of motile microorganisms. $Nb=\frac{\tau D_B\Delta C_w}{\alpha}$ is the Brownian motion parameter, $Nt=\frac{\tau D_T\Delta T_w}{\alpha T_\infty}$ is the thermophoresis parameter, $Ec=\frac{\alpha^2 Ra_x^{\frac{1}{2}}}{x^2C_p\Delta T_f}$ is the modified Eckert number, $Pr=\frac{V_f}{\alpha}$ is the Prandtl number, $Q=\frac{Q_o x^2}{(\rho C)_f Ra_x^{\frac{1}{2}}V_f}$ is the heat generation, $M = \frac{\sigma B_0^2 x^2}{\mu_f Ra_x^{\frac{1}{2}}}$ is the modified magnetic parameter, $f_{w=} - \frac{xV_w}{\alpha Ra_x^{\frac{1}{4}}}$ is the suction/injection parameter, $Lb = \frac{\alpha}{D_m}$ is the bioconvection Lewis number, $Le = \frac{\alpha}{D_B}$ traditional Lewis number, $Pe = \frac{bW_C}{D_m}$ is the bioconvection Peclet number, $Nr = \frac{(\rho_p - \rho_{f\infty})\Delta C_w}{\rho_f(1-\emptyset_\infty)\beta\Delta T_w}$ is the buoyancy ratio parameter, $\sigma = \frac{n_\infty}{\Delta n_w}$ is the bioconvection constant, $Rb = \frac{\gamma \Delta n_w \Delta\rho}{\rho_f(1-\emptyset_\infty)\beta\Delta T_w}$ is the bioconvection Rayleigh number, $Da^{-1} = \frac{\varepsilon x^2}{kRa_x^{1/2}}$ is the inverse Darcy number, $Kr = \frac{k_r x^2}{D_B Ra_x^{1/2}}$ is the chemical reaction rate parameter, $\lambda = \frac{N_1 Ra_x^{1/4}}{x}$ is the slip parameter. Furthermore, K_r indicate the constant rate of chemical reaction between the base fluid where $K_r > 0$ for destructive reaction, $K_r < 0$ for generative reaction and $K_r = 0$ indicate for no chemical reaction.

The physical interest such as the local Nusselt number Nu_x, Sherwood number Sh_x and local density number of the motile microorganisms Nn_x are defined as [3]

$$Nu_x = \frac{xq_w}{k\Delta T}, \tag{13}$$

$$Sh_x = \frac{xD_B q_m}{D_m \Delta C}, \tag{14}$$

$$Nn_x = \frac{xq_n}{D_n \Delta n}. \tag{15}$$

In which $q_w = -k(\frac{\partial T}{\partial y})_{y=0}, q_m = -D_B(\frac{\partial C}{\partial y})_{y=0}$ and $q_n = -D_n(\frac{\partial n}{\partial y})_{y=0}$ are the wall heat, the wall mass and the wall motile microorganisms fluxes, respectively. Substituting equation (7) into equations (13), (14), and (15), the local Nusselt number, Sherwood number, and the local density number of the motile microorganisms by [3] and [18]

$$Nur = Ra_x^{-\frac{1}{4}}(\frac{-x^{\frac{3}{4}}\theta'(0)(T_w - T_\infty)A}{\Delta T}) = -\theta'(0), \tag{16a}$$

$$Shr = Ra_x^{-\frac{1}{4}}(\frac{-x^{\frac{3}{4}}\left(A\phi'(C_w - C_\infty)\right)}{\Delta C}) = -\emptyset'(0), \tag{16b}$$

$$Nnr = Ra_x^{-\frac{1}{4}}(\frac{-x^{\frac{3}{4}}\chi'(0)(n_w - n_\infty)A}{\Delta n}) = -\chi'(0), \tag{16c}$$

where $Ra_x = \frac{(1-\phi_\infty)\beta g \Delta T_f}{\alpha v} x^3$ is the local Rayleigh number.

Numerical Computation and Validation

Equations (8) to (12) are numerically solved using the bvp5c solver in MATLAB software. In order to solve the problem using bvp5c, we begin by transforming the ODEs into a system of first-order ODEs through the introduction of new variables, such as

$$(y1, y2, y3, y4, y5, y6, y7, y8, y9) = (f, f', f'', \theta, \theta', \emptyset, \emptyset', \chi, \chi'). \tag{17}$$

By using Equation (17), Equations (8) to (11) becomes

$$\begin{aligned} y_1' &= y_2, \\ y_2' &= y_3, \\ y_3' &= -\frac{3}{4Pr}y_1 y_3 + \frac{1}{2Pr}y_2 y_2 - y_4 + Nry_6 + Rby_8 + Da^{-1}y_2, \\ y_4' &= y_5, \end{aligned} \tag{18}$$

$$y_5' = -\tfrac{3}{4}y_1y_5 - Nby_7y_5 - Nty_5y_5 - EcPr(y_3y_3 + My_2y_2) - PrQy_4,$$

$$y_6' = y_7,$$

$$y_7' = -\tfrac{3}{4}Ley_1y_7 - \tfrac{Nt}{Nb}y_5' + Kry_6,$$

$$y_8' = y_9,$$

$$y_9' = -\frac{3}{4}Lby_1y_9 + Pe[y_7y_9 + y_7{}'(\sigma + y_8)].$$

Along with the transformed boundary conditions

at $\eta = 0$: $y_1(0) = f_w, y_2(0) = \lambda y_3, y_4(0) = 1, y_6(0) = 1, y_8(0) = 1,$ (19a)

as $\eta \to \infty$: $y_2(\infty) \to 0, y_4(\infty) \to 0, y_6(\infty) \to 0, y_8(\infty) \to 0.$ (19b)

The results of the current study for the reduced Nusselt number are validated against previous published results by researchers [20], [18], and [3]. By letting $M = \lambda = Rb = Lb = Ec = 0, Nt = Nb = Nr = 10^{-5}, Le = 10,$ Table 1 is computed, the present computed results are well agreed with the existing results. The validation of the results shown in the current study is confirmed. This confirms the confidence in the validity of the present computed numerical results and the reliability of the analysis in the following section.

Table 1. Results validation for Nusselt number, $-\theta'(0)$ for various values of Prandtl number, Pr

Pr	$-\boldsymbol{\theta}'(\mathbf{0})$			
	Kuznetsov and Nield [20]	Khan et al. [18]	Kalidas et al. [3]	Present result
1	0.401	0.40135	0.401452	0.392187
10	0.449	0.46903	0.469315	0.460522
100	0.458	0.49260	0.492529	0.485248
1000	0.459	0.49878	0.498650	0.490042

3 Results and discussion

The impacts of physical parameters including chemical reaction (Kr), heat generation (Q), thermal radiation (Rb), inverse Darcy number (Da^{-1}), slip parameter (λ) and as shown in Figures 2-5. The parameter values is specified in the range of $Rb\,\{0.0,0.3,1.0\}, Da^{-1}\{0.0,0.5,1.0,1.5\}$, $Kr\{0.0,0.2,0.6,0.8\}$, $Q\{0.1,0.5,0.7,1.5\}$ and $\lambda\{0.0,0.1,0.2,0.3\}$ as given in [18] and [3]. The graphs are plotted using the choice of parameter values as following $Pr = 6.2, M = 1.0, Rb = 0.3, Nb = 0.2, Nt = 0.1, Ec = 0.1, Q = 0.0,$ $Le = 1.0, Lb = 0.3, \sigma = 0.5, f_w = 0.5 \text{ or} 0.5, Da^{-1} = 0.5, \lambda = 0.1 \text{ and } Kr = 0.3$ by [18] and [3].

Figure 2 display the behavior of velocity profiles with various values of inverse Darcy number, Da^{-1} on with and without bioconvection Rayleigh number, Rb. From the graph, velocity profiles consistently show higher velocities without Rb compared to with Rb. At higher values of Da^{-1} which indicate lower permeability, the medium itself offers significant resistance to flow. In such cases, the additional driving force from bioconvection might not be sufficient to overcome this resistance, leading to lower observed velocities. Besides that, lower values of Da^{-1} resulting in higher velocity profiles rather than higher values of Da^{-1} due to the porous medium offers less resistance to flow for lower values of Da^{-1}. The velocity tends to be higher in the centre of the flow channel and lower near the boundaries due to minimal frictional resistance. In the presence of the bioconvection Rayleigh number, Rb, buoyancy-driven forces created by the activity of microorganisms lead to increased fluid motion.

The influence of various values of slip parameter, λ on velocity profiles with and without bioconvection Rayleigh number, Rb is illustrated in Figure 3. The presence of bioconvection Rayleigh number introduces a buoyancy force that opposes the main flow direction, reducing the velocity profile compared to the case without bioconvection Rayleigh number. Near the surface, velocity profiles decrease because without slip velocity, the fluid velocity at the boundary is zero that will creating a steep velocity gradient. Slip conditions allow some fluid movement at the boundary, reducing resistance and resulting in higher velocities near the surface. Opposite behavior is observed on the surface, when particles that farther away from surface, no slip velocities become higher compared to slip velocities. This happens because the fluid in no-slip conditions accumulates more momentum transfer from the boundary layer as it moves away from the surface lead to higher velocities. In slip conditions, the reduced drag near the surface results in less momentum transfer to the fluid farther away lead to lower velocities in that region.

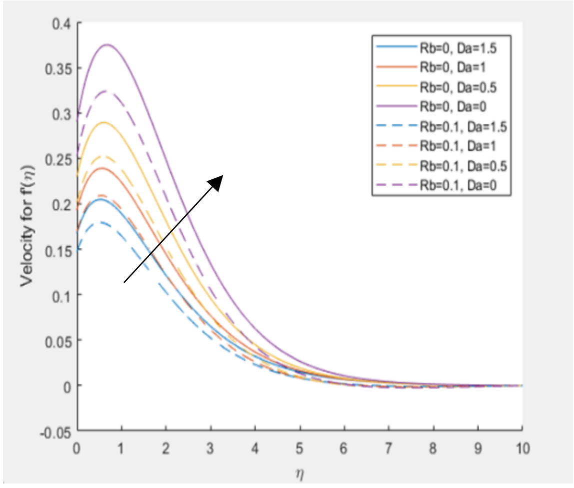

Figure 2 The effect of the inverse Darcy number, Da^{-1} on velocity profiles with and without bioconvection Rayleigh number, Rb

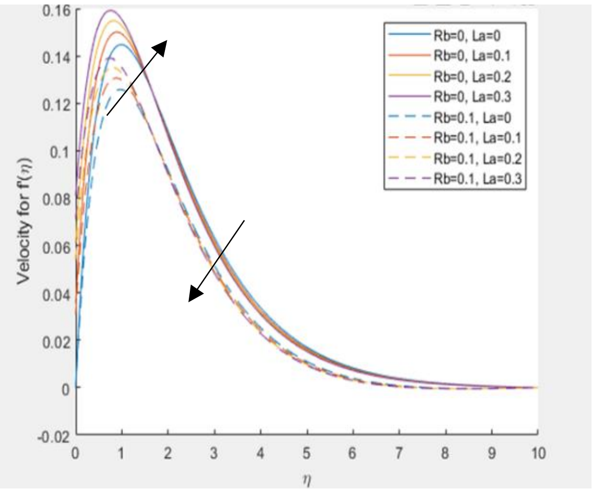

Figure 3 The effect of the slip parameter on Velocity profiles with and without bioconvection Rayleigh number, Rb

Furthermore, Figure 4 exhibits the concentration distribution for various values of the chemical reaction parameter $Kr\ (>0)$ in presence of bioconvection. This effect explains that the mass transfer rate enhances due to a high destructive chemical rate, resulting in a drop in concentration and gyrotactic microorganisms of the fluid across the boundary layer region. Kalidas et al. (2015) stated that the concentration of the fluid gradually changes from the higher value to the lower value only when the strength of the rate of chemical reaction is higher than the kinematic viscosity of the fluid.

Figure 5 exhibits the temperature distribution for various values of heat generation parameters, Q. Increasing the heat generation can result in lower temperature profiles because the added heat enhances the convective currents within the fluid. These microorganisms, such as certain algae, tend to swim upwards due to their gyrotactic behaviour and creating a convective flow that brings cooler fluid from the upper regions downward. When heat generation is increased, the convective mixing becomes more vigorous, distributing the heat more efficiently throughout the fluid. This enhanced mixing helps to dissipate the heat which lead to a more uniform temperature distribution and preventing localized temperature spikes thus lowering the overall temperature profile.

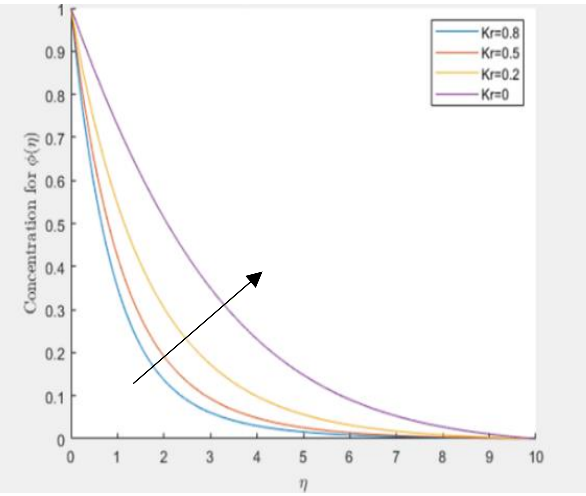

Figure 4 The effect of the Chemical Reaction,Kr on Concentration profiles

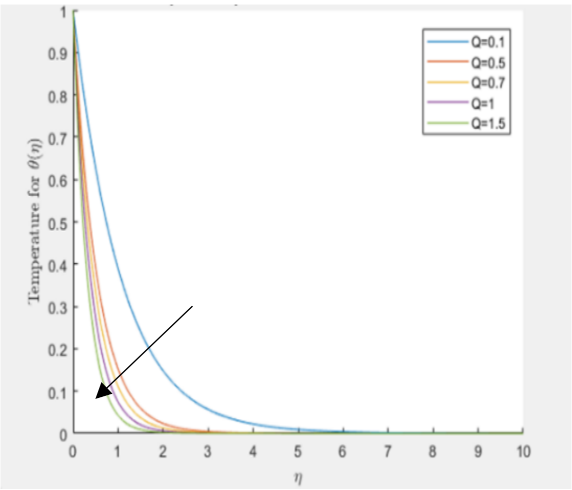

Figure 5 The effect of Heat Generation,Q on Temperature profile

Tables 2-5 show how the inverse Darcy number, chemical reaction, slip velocity and heat generation parameter affect the Nusselt number, Sherwood number, and density number of the motile microorganisms. In Table 2, as the increasing of inverse Darcy number, the rates of heat and mass transfer increases but the local Sherwood number and local density number of motile microorganisms is reducing. Table 3 indicates that the rate of mass transfer and motile microorganisms flux at the wall of the permeable stretching surface would be increased with increase in chemical reaction parameter. In Table 4, as slip velocity parameter increase, local Nusselt number, local Sherwood number, and density of motile microorganisms are increasing as well. In Table 5, as heat generation parameter increases, the local Sherwood number decreases but the heat and mass transfer rates increase respectively.

Table 2 Quantities of interest with inverse Darcy number parameter, Da^{-1}

Da^{-1}	Nusselt number, Nur	Sherwood number, Shr	Density number of motile microorganisms, Nnr
0.0	0.2609	0.8930	1.012
0.5	0.2644	0.8542	0.9637
1.0	0.2648	0.8002	0.9356
1.5	0.2763	0.7293	0.9021
2.0	0.2841	0.6001	0.8939

Table 3 Quantities of interest with Chemical Reaction parameter, Kr

Kr	Nusselt number, Nur	Sherwood number, Shr	Density number of motile microorganisms, Nnr
0.0	0.3780	0.5147	0.9903
0.2	0.4867	0.5470	1.3854
0.4	0.4875	0.6056	1.3959
0.6	0.5055	0.6233	1.4000
0.8	0.5732	0.7731	1.4023

Table 4 Quantities of interest with Slip Velocity parameter, λ

λ	Nusselt number, Nur	Sherwood number, Shr	Density number of motile microorganisms, Nnr
0.1	0.3661	0.5502	0.2014
0.2	0.3800	0.5711	0.2096
0.3	0.3950	0.5927	0.2184

Table 5 Quantities of interest with Heat Generation parameter, Q

Q	Nusselt number, Nur	Sherwood number, Shr	Density number of motile microorganisms, Nnr
0.1	2.2563	0.9673	0.2348
0.2	2.3641	0.9551	0.2140
0.3	2.3652	0.9543	0.2061
0.4	2.4003	0.9340	0.1996

0.4	0.4005	0.6083	0.2268
0.5	0.4172	0.6261	0.2324

0.5	2.4762	0.9133	0.1867

4 Conclusion

The present study investigates bioconvection driven by motile gyrotactic microorganisms and chemical reaction past a permeable slip vertical plate embedded in a porous medium, with internal heat generation. The problem is mathematically modelled that include continuity, momentum, energy, concentration, and density of motile microorganisms. Then, a similarity transformation is used to reduce the dimensional partial differential equations to dimensionless ordinary differential equations. These equations are numerically solved using the bvp5c solver in MATLAB software. To ensure the accuracy of the algorithm developed in MATLAB software, the numerical results of the Nusselt number coefficient are validated with existing results from previously published papers. Moreover, the impacts of physical parameters such as the Nusselt number, Sherwood number, and density number of the motile microorganisms are studied. The various parameters including the chemical reaction, heat generation, bioconvection Rayleigh number, inverse Darcy number and slip parameter, are examined. The significant outcomes of the study are as follows:

I. The inverse Darcy number reduces the thickness of the hydrodynamic boundary layer. Additionally, the fluid velocity decreases in the presence of bioconvection.
II. Increasing the slip parameter causes the velocity profiles to shift upward, indicating higher fluid velocities.
III. The concentration decreases with an increase in the destructive chemical reaction rate parameter.
IV. Higher temperature difference ratio and heat generation parameter temperature exhibits growing behaviour.
V. These findings can be utilized in the design and operation of systems such as heat exchangers, cooling systems, microfluidic devices, environmental remediation processes, and bioreactors. Ultimately, this leads to improved energy efficiency, pollutant removal, and system reliability.

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