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Exploring the Impact of Thermal Radiation and Viscous Dissipation on Magnetohydrodynamic (MHD) Bioconvection Flow of Maxwell Nanofluid along a Porous Vertical Plate Driven by Gyrotactic Microorganisms.

K saikumar, Koneru Lakshmaiah Education Foundation, India-522302, saikumarkayam4@ieee.org

SK ahammad , Koneru Lakshmaiah Education Foundation, India-522302,

Abstract

This article explores the impacts of thermal radiation and viscous dissipation on the magnetohydrodynamic (MHD) bioconvection flow of a novel type of water-based upper-convected Maxwell nanoliquid containing nanoparticles and motile gyrotactic microorganisms over an absorptive vertical moving plate. The bioconvection in the nanoliquid is generated through the combined influences of buoyant forces and a magnetic field on the interplay between motile microorganisms and nanoparticles. The governing nonlinear partial differential equations of the problem are transformed into a set of nonlinear ordinary differential equations using suitable similarity transformations and a shooting method approach. The comprehensive flow regime is analysed parametrically to illustrate the effects of key parameters, namely the bioconvection Lewis number (Lb), traditional Lewis number (Le), bioconvection Peclet number (Pe), buoyancy ratio (Nr), bioconvection Rayleigh number (Rb), Brownian motion parameter (Nb), thermophoresis parameter (Nt), Hartmann number (Ha), Grashof number (Gr), radiation parameter (R), Eckert number (Ec), microorganisms concentration variation parameter (Ω), and suction/injection parameter (fw) on the flow, temperature, volume fraction of nanoparticles, and density profiles of motile microorganisms.

Introduction

Bioconvection flow is a phenomenon observed when a substantial convective motion of the liquid arises due to the density gradient induced by the collective rotational movement of microorganisms. These self-propelled motile microorganisms tend to aggregate near the upper region of the liquid layer, resulting in a thicker upper layer compared to the lower region. This accumulation leads to variations in the liquid's characteristics, giving rise to diverse flow patterns within the system [1-3]. Bioconvection finds numerous applications in the realms of biology and bio-microsystems. For instance, it plays a role in enzyme biosensors and biotechnology by enhancing momentum transport and cooperation, crucial factors in various micro-systems [4]. Bioconvection theory also holds potential for microbial enhanced oil recovery, where microorganisms and nutrients are introduced into oil-bearing layers to mitigate permeability disparities. Moreover, the unique spinning ability of motile microorganisms can be harnessed for extracting information from cells, purifying substances, and distinguishing between different sub-populations (e.g., discerning between swift and sluggish swimmers) [5-7]. However, it's important to note that in certain scenarios, such as those involving dissimilar types of cells, effective separation through bioconvection might not be achievable due to the tendency for collaboration among various cell types [8]-[9].

Mathematical formulation

We examine a steady boundary layer flow of an electrically conductive water-based upper-convected Maxwell nanoliquid containing gyrotactic microorganisms adjacent to a permeable vertical flat plate under the influence of thermal radiation [10-12]. The flow is exposed to a uniform transverse magnetic field with a specified strength. the boundary-layer estimates of the continuity, momentum, energy, nanoparticle concentration and conservation for micro-organisms equations are:

(i) Continuity:

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

(ii) Momentum:

$$\begin{aligned} u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=&-\frac{1}{\rho_f}\frac{\partial p}{\partial y}+v_f\frac{\partial^2 u}{\partial y^2}+k_1\frac{\partial N}{\partial y}-\frac{\sigma B_0^2 u}{\rho_f} \\ &+k_0\left[u^2\frac{\partial^2 u}{\partial x^2}+v^2\frac{\partial^2 u}{\partial y^2}+2uv\frac{\partial^2 u}{\partial x\partial y}\right] \\ &+\frac{1}{\rho_f}\Big[(1-\phi_\infty)\,\rho_f\beta g(T-T_\infty)-(\rho_p-\rho_f)g(\phi-\phi_\infty) \\ &\quad -(\rho_m-\rho_f)g\gamma(n-n_\infty)\Big] \end{aligned} \tag{2}$$

(iii) Equation of energy:

$$\begin{aligned} u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=&\,\alpha\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)-\frac{1}{\rho c_p}\frac{\partial q_r}{\partial x} \\ &+\tau\left\{D_B\frac{\partial \phi}{\partial y}\frac{\partial T}{\partial y}+\left(\frac{D_T}{D_\infty}\right)\left[\left(\frac{\partial T}{\partial x}\right)^2+\left(\frac{\partial T}{\partial y}\right)^2\right]\right\} \\ &+\frac{v\alpha}{k}\left(\frac{\partial u}{\partial y}\right)^2+\frac{\alpha\sigma B_0^2 u^2}{k} \end{aligned} \tag{3}$$

(iv) Concentration of nanoparticle:

$$u\frac{\partial \phi}{\partial x}+v\frac{\partial \phi}{\partial y}=D_B\left(\frac{\partial^2 \phi}{\partial x^2}+\frac{\partial^2 \phi}{\partial y^2}\right)+\left(\frac{D_T}{D_\infty}\right)\left[\left(\frac{\partial T}{\partial x}\right)^2+\left(\frac{\partial T}{\partial y}\right)^2\right] \tag{4}$$

(v) Conservation of microorganisms:

$$\begin{aligned} &u\frac{\partial n}{\partial x}+v\frac{\partial n}{\partial y}+\frac{bW_C}{(\phi_w-\phi_\infty)}\left[\frac{\partial}{\partial x}\left(n\frac{\partial \phi}{\partial x}\right)+\frac{\partial}{\partial y}n\left(\frac{\partial \phi}{\partial y}\right)\right] \\ &=D_B\left(\frac{\partial^2 n}{\partial x^2}+\frac{\partial^2 n}{\partial y^2}+\frac{\partial^2 n}{\partial x \partial y}\right) \end{aligned} \tag{5}$$

Numerical procedure

New variables are generated…

$$\begin{aligned} &x_1 = f, x_2 = f', x_3 = f'', \\ &x_4 = \theta, x_5 = \theta', x_6 = \xi, \\ &x_7 = \xi', x_8 = \chi, x_9 = \chi' \end{aligned}$$

$$x_3' = -x_1 x_3 + x_2^2 + Hax_2 - Gr(x_4 - Nrx_6 - Rbx_8)$$

$$\begin{aligned} x_5' &= -\frac{1}{(1+4R/3)}x_5(\Pr x_1 - Nbx_7) \\ &-\mathrm{Nt}\, x_5^2 - \Pr Ec(x_3^2 + Hax_2^2) \end{aligned}$$

$$\begin{aligned} x_7' &= -Lex_1 x_7 \\ &-\frac{\mathrm{Nt}}{Nb}\left[-x_5(\Pr x_1 - Nbx_7) - \mathrm{Nt}\, x_5^2 - \Pr Ec(x_3^2 + Hax_2^2)\right] \end{aligned}$$

$$\begin{aligned} x_9' &= -Lbx_1 x_9 - Pe\Big\{\left(x_8 + \Omega\right)\Big[-Lex_1 x_7 \\ &-\frac{\mathrm{Nt}}{Nb}\begin{bmatrix} -x_5(\Pr x_1 - Nbx_7) \\ -\mathrm{Nt}\, x_5^2 - \Pr Ec(x_3^2 + Hax_2^2) + x_7 x_9 \end{bmatrix}\Big]\Big\} \end{aligned}$$

subject to the following initial conditions.

$$\begin{aligned} &x_1(0) = \mathrm{fw},\ x_2(0) = 1,\ x_3(0) = s_1,\ x_4(0) = 1, \\ &x_5(0) = s_2, x_6(0) =, x_7(0) = s_3, x_8(0) =, x_9(0) = s_4 \end{aligned}$$

Results

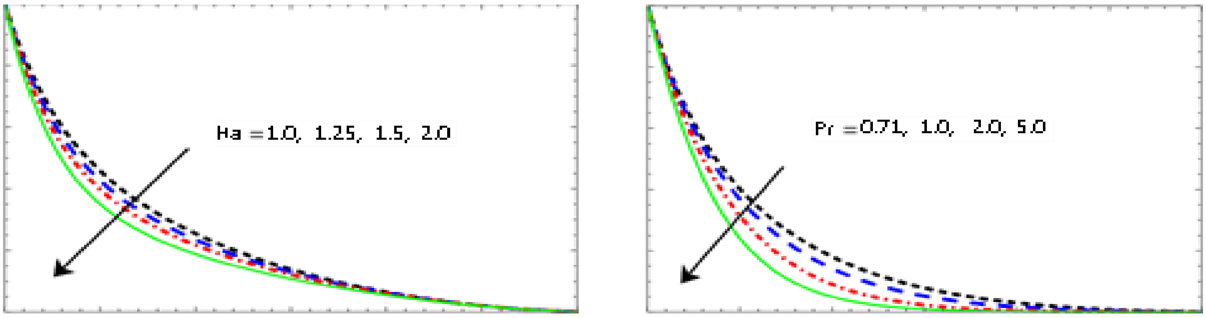

Figure 1 & 2: influence of Ha and Pr

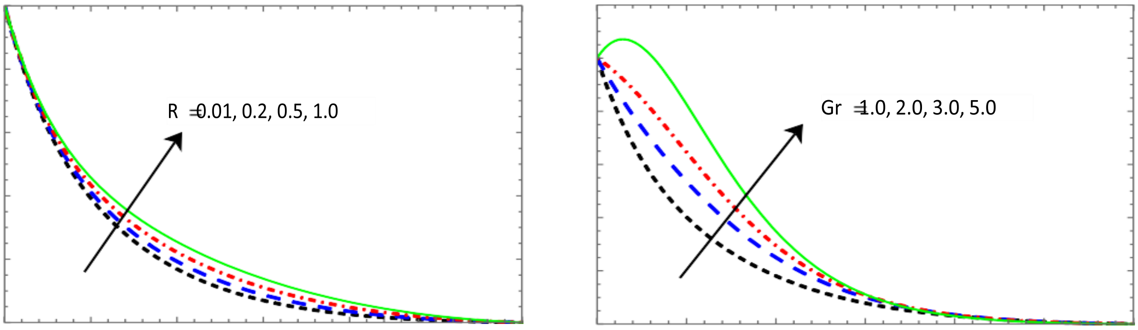

Figure 3 & 4: influence on R and Gr

Conclusion

Numerical analysis is employed to study the boundary layer flow of a water-based nanoliquid containing mobile microorganisms flowing past a vertical permeable flat plate. The convective process is governed by the buoyancy parameter Nr, along with the bioconvection parameters Pe, Lb, and Rb.

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