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ORIGINAL ARTICLE

Framing the impact of external magnetic field on bioconvection of a nanofluid flow containing gyrotactic microorganisms with convective boundary conditions

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Abstract The intention of this study is to examine the combined impacts of magnetic field and convective boundary state on bioconvection of a nanofluid flow along an expanding sheet co-existed with gyrotactic microorganisms. The fundamental partial differential equations are reduced to a set of nonlinear ordinary differential equations taking a guide of some appropriate similarity transformations. The numerical fallouts are calculated by considering the bvp4c function of Matlab. The impacts of magnetic field parameter, surface convection parameter, Eckert number and Peclet number on non-dimensional velocity, nanoparticle concentration, temperature and density of self-moving microorganisms are interpreted through graphs and charts. The fluid velocity near the surface and the Nusselt number is lessen with magnetic field. Surface convection parameter enhances the self-moving microorganism flux but a reverse result is noticed for Peclet number. Also, the contrast between the present results with formerly visited outcomes is in excellent harmony.

1. Introduction

Bioconvection is the unprompted configuration of macroscopical fluid patterns, such as declining plumes. There are mainly two types of up swimming micro-organisms that are generally applied in bioconvection experiments: bottom-heavy algae and firm oxytactic bacteria. The bioconvection structures created by microorganisms are similar although, the mechanisms of direction are different [1]. This guides to the development of hydrodynamic instability under definite circumstances. The motile micro-organisms are self-urged which enlarges the denseness of the primary fluid by swimming toward a particular direction within the liquid in attraction to stimulus such as oxygen, daylight, gravity whereas nanoparticles cannot swim. The random motions of nanoparticles generate owing to the Brownian and thermophoresis diffusion property and are

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carried by the drift of the primary fluid. Nanofluids have significant usage in micro fluidic devices since they are very helpful for mass transport enhancement and induce mixing, especially in micro volumes. Sheikholeslami and Ellahi [2] observed the influence of non-uniform electric field on nanofluid in an enclosure with sinusoidal upper wall. Effect of thermal radiation on nanofluid using two phase model was analyzed by Sheikholeslami et al. [3]. A sensitivity analysis is done by Akbarzadeh et al. [4] on thermal and pumping power of nanofluid. The thought of bioconvection of nanofluid with gyrotactic microorganisms was pioneered by Kuznetsov [5]. Usually, bioconvection in nanofluids arises when the concentration of nanoparticles is small ($\leqslant 1\%$) therefore, the viscous property of the primary fluid does not alter significantly. For practical purpose, at fundamental level, the nature of suspensions carrying both nanoparticles and self-swimming microorganisms in microsystems must be understood. One of the popular applications of bioconvection in bio-microsystems is the improvement of mass transport capability and mixing [6,7]. There is also important potential in applying nanofluids in various bio-microsystems, namely the optimization of celluloses production, enzyme biosensors [8], chip-shaped microdevices using to evaluate toxicity of nanoparticles [9] and provocative response of the lung to silica nanoparticles [10] and Kuznetsov with Avramenko [11] first introduced the bioconvection problem containing tiny solid particles as well as gyrotactic microorganisms. The idea of Kuznetsov and Avramenko [11] has been implemented by several new researchers [12–19] in bioconvection of nanofluid flow with gyrotactic microorganisms. Xu and Pop [20] encountered a mixed convection situation of a nanofluid caring both gyrotactic microorganisms and nanoparticles.

The work on magnetic impacts has important applications in mechanical engineering as well as in physics. Much equipments for example, the magnetohydrodynamic generators, pumps, bearings, and the boundary layer monitoring in the field of aerodynamics, thermal insulators, and microelectronic devices are influenced by the interaction between the electrically transit fluid and a magnetic flux. There are abundant amount of research works present on the impact of magnetic field on the boundary region flow and heat diffusion of primary fluid as well as for nanofluid with different flow situations but, some of the recent research works with magnificent applications are referred here ([21–25]). The influence of magnetic flux on nanofluid flow is effectively observed in biomedical engineering such as nanoparticles are treated as delivery medium for cancer treatment procedure. Such nanoparticles can be traveled in the bloodstream applying magnetic field outwardly to the frame. Kandelousi and Ellahi [26] examined the simulation of ferrofluid flow for magnetic drug targeting. MHD nanofluid flow containing carbon nanotubes suspended in a salt water solution was studied by Ellahi et al. [27]. In several situations where an enhancement in heat transport usefulness can be advantageous to the quality, quantity and the cost of a product or process, nanofluids work effectively coexisting with magnetic field. In accordance with the author, a plenty of studies ([28–31]) have so long been in circulation on the boundary region flow along with heat transport in a nanofluid along an expanding surface in coexistence of external magnetic flux.

It is noticed from the prior research works that the boundary circumstances are considered in the fluid flow situations are either at a particular wall temperature or at a specified surface heat flow. In most of the situations for simplicity the dependency relation between the surface heat diffusion and surface temperature is assumed to be linear. The conjugate convective flow is the state by means of Newtonian heating where the heat is supplied to the fluid through a surrounding surface. In this state the speed of heat transmission through a given region is proportional to the variation of wall temperature and the ambient condition. The different boundary layer flow problems coexisting convective boundary situation were faced by Aziz [32], Ishak [33] and Makinde and Aziz [34], and Aziz and Khan [35]. Of late, the nanofluid flow along an expanding surface coexistence with convective boundary conditions was analyzed by Das et al. [36].

The aim of this approach is to offer a new type of primary fluid comprising nanoparticles and gyrotactic microorganisms coexistence of magnetic field, viscous dissipation along with convective boundary situation. It is hoped that the present work will serve as a stimulus for needed experimental work on this problem. The model offers design guidelines for the development of healthy production of fertilizer and polymer substances. The remaining work is designed as follows: the mathematical formulations of the fundamental equations along with boundary conditions are derived in segment 2; numerical procedure is narrated in segment 3; the fallouts of numerical solutions and discourses are given through segment 4 and finally ultimate comments are drawn in segment 5.

2. Mathematical formulation

Here, we consider a nanofluid where the primary liquid is water, comprising electrically conducting nano solid particles and gyrotactic microorganisms. We suppose that the suspension of nano solid particles to be static and does not tend to conglomerate within fluid medium. It is also assumed that the presence of nanoparticles does not possess any effect on the swimming route as well as on the velocity of swim of microorganisms. This hypothesis is defensible only when nanoparticles concentration is lesser than 1%. So, for bioconvection stability, it is assumed that the suspensions of nano solid particles are diluted in the liquid medium. A coordinate is framed having the starting point at the bottom corner of this sheet, where the x – axis remains upright and the y – axis stands perpendicular to the vertical. The motion of nanofluid extends to $y > 0$. Two similar forces are applied to x – axis but from opposite directions such that the sheet is expanded maintaining the origin fixed as shown in Fig. 1. The expanded plate shifts along its surface with the stretching velocity $u_w = ax$ with "a" as a positive constant. A lateral magnetic flux with uniform potency B_0 is implemented perpendicularly to the plate. It is to be regarded that there is no prevalence of outwardly implemented electric field. Magnetic Reynolds number is negligible; therefore, the internal magnetic flux is inconsiderable compared to outwardly implemented magnetic flux. Under the above stated considerations, the fundamental equations can be gained from model projected by Xu and Pop [20] as follows:

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