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Full Length Article

Perturbation analysis of magnetohydrodynamics oscillatory flow on convective-radiative heat and mass transfer of micropolar fluid in a porous medium with chemical reaction

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ABSTRACT

This paper deals with the perturbation analysis of mixed convection heat and mass transfer of an oscillatory viscous electrically conducting micropolar fluid over an infinite moving permeable plate embedded in a saturated porous medium in the presence of transverse magnetic field. Analytical solutions are obtained for the governing basic equations. The effects of permeability, chemical reaction, viscous dissipation, magnetic field parameter and thermal radiation on the velocity distribution, micro-rotation, skin friction and wall couple stress coefficients are analyzed in detail. The results indicate that the effect of increasing the chemical reaction has a tendency to decrease the skin friction coefficient at the wall, while opposite trend is seen by increasing the permeability parameter of the porous medium. Also micro-rotational velocity distribution increases with an increase in the magnetic field parameter.

1. Introduction

There has been a considerable amount of interest among researchers to study the convective flow with simultaneous heat and mass transfer under the influence of a magnetic field and chemical reaction as such processes exist in many branches of science and technology. In many industries application of such type of problems are seen in the chemical industry, cooling of nuclear reactors and magnetohydrodynamic (MHD) power generators. The study of MHD mixed convection heat and mass transfer with chemical reaction are of great importance to engineers and scientists because of its almost universal occurrence in many branches of science and engineering, and hence received a considerable amount of attention in recent years. The study of heat transfer in porous medium in the presence of chemical reaction has important engineering applications e.g. oxidation of solid materials, synthesis of ceramic materials and tubular reactors. There are two types of reactions such as (i) homogeneous reaction and (ii) heterogeneous reaction. A homogeneous reaction occurs uniformly throughout the given phase, whereas heterogeneous reaction takes place in a restricted region or within the boundary of a phase. The effects of a chemical reaction depend greatly on whether the reaction is heterogeneous or homogeneous. A chemical reaction is said to be first-order if the rate of reaction is directly proportional to the concentration itself. In many industrial processes involving flow and mass transfer over a moving surface, the diffusing species can be generated or absorbed due to some kind of chemical reaction with the ambient fluid which can greatly affect the flow and hence the properties and quality of the final product. These processes take place in numerous industrial applications, such as in the polymer production and in manufacturing of ceramics or glassware, and food processing chemical reaction that occurs between a foreign mass and a fluid in which a plate is moving. Ibrahim et al. [1] studied the effect of chemical reaction and thermal radiation absorption on the unsteady MHD free convection flow past a semi-infinite vertical permeable moving plate with heat source and suction. They found that the velocity profiles and concentration profile increased due to a decrease in the chemical reaction parameter. Al-Odat and Al-Azab [2] studied the influence of chemical reaction on transient MHD free convection over a moving vertical plate. They found that the velocity as well as concentration decrease with increasing the chemical reaction parameter. Seddeek et al. [3] examined the effects of chemical reaction and variable viscosity on hydromagnetic mixed convection heat and mass transfer for Hiemenz flow through porous media with radiation, and they found that the local

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Sherwood number significantly increases with the chemical reaction parameter. Pal and Talukdar [4] used perturbation analysis to study unsteady magnetohydrodynamic convective heat and mass transfer in a boundary layer slip flow past a vertical permeable plate with thermal radiation and chemical reaction. They solved the nonlinear coupled partial differential equations by perturbation technique and found that the velocity as well as concentration decrease with increasing the chemical reaction parameter. Hsiao [5] studied the heat and mass transfer on MHD mixed convection of viscoelastic fluid past a stretching sheet with Ohmic dissipation. Rout et al. [6] studied the effect of thermal radiation and chemical reaction on double diffusive natural convective MHD flow through a porous medium. They considered destructive reaction in this paper, i.e., when chemical reaction parameter is positive then the concentration decreases due to the contribution of mass diffusion in concentration equation, while in the generative reaction, i.e., when chemical reaction parameter is negative, they observed the reverse effect. They further found that with increasing chemical reaction parameter there is substantial increase in the temperature profile.

Mixed convection in porous media has gained significant attention for its importance in engineering applications such as in the design of nuclear reactor, ceramics processing, geothermal systems, solid matrix heat exchangers, thermal insulations, crude oil drilling and compact heat exchanges etc. Convection in porous media can also be applied to underground coal gasification, ground water hydrology, iron blast furnaces, wall cooled catalytic reactors, energy efficient drying processes, cooling of nuclear fuel in shipping flasks, cooling of electronic equipments and natural convection in the Earth's crust. The fundamental problem of flow through and past porous media has been studied extensively over the past few years both theoretically and experimentally. Modather et al. [7] analytically studied MHD heat and mass transfer oscillatory flow of a micropolar fluid over a vertical permeable plate in a porous medium, and the results indicate that increasing the permeability parameter produces an increasing effect on the skin friction coefficient and the couple stress coefficient at the wall. El-Hakiem [8] examined the MHD oscillatory flow on free convection-radiation through a porous medium with constant suction velocity. They observed that the velocity increases when the permeability of the porous medium is increased. Pal and Talukdar [9] investigated the buoyancy and chemical reaction effects on MHD mixed convection heat and mass transfer in a porous medium with thermal radiation and Ohmic heating, and they concluded that the presence of porous medium increases the skin friction coefficient, whereas the effect of increasing the value of porous permeability decrease the value of the local Nusselt number. Sugunamma et al. [10] studied the inclined magnetic field and chemical reaction effects on flow over a semi-infinite vertical porous plate through porous medium. They solved the non-linear and coupled governing equations by adopting a perturbative series expansion about a small parameter, ε, and they observed that the velocity gradient at the surface increases with a decrease in the porosity parameter. Acharya et al. [11] analyzed the free convective fluctuating MHD flow through porous media past a vertical porous plate with variable temperature and heat source, and they recorded that the presence of porous media has no significant contribution to the flow characteristics whereas viscous dissipation compensates for the heating and cooling of the plate due to convective current.

The study of free convection flow with magnetic field plays a major role in liquid metals, electrolytes and ionized gases and thermal physics of hydromagnetic problems with mass transfer have enormous applications in power engineering. Prasad et al. [12] examined the influence of internal heat generation/absorption, thermal radiation, magnetic field, variable fluid property and viscous dissipation on heat transfer characteristics of a Maxwell fluid over a stretching sheet, and they have pointed out that the horizontal velocity decreases with an increase in the magnetic field parameter. They concluded that this is due to the fact that the transverse magnetic field has a tendency to create a drag like force, known as the Lorentz force to resist the flow. Vija et al. [13] studied the effects of induced magnetic field and viscous dissipation on MHD mixed convective flow past a vertical plate in the presence of thermal radiation. They found that the values of induced magnetic field remained negative, i.e. induced magnetic flux reversal arises for all distances in the boundary layer.

The effects of radiation on MHD flow and heat transfer problems have become industrially more important. The thermal radiation effects become intensified at high absolute temperature levels due to basic difference between radiation and the convection and conduction energy-exchange mechanisms. Many engineering processes occur at high temperatures and hence the knowledge of thermal radiation heat transfer is essential for designing appropriate equipments such as nuclear power plants, gas turbines and various propulsion devices for aircraft, missiles and satellites. When radiative heat transfer takes place in the electrically conducting fluid, it is ionized due to the high operating temperature. In view of these, many authors have made contributions to the study of fluid flow with thermal radiation. Hsiao [14] analyzed heat and mass transfer of micropolar fluid flow in the presence of thermal radiation past a nonlinearly stretching sheet. Shateyi et al. [15] investigated the effects of thermal radiation, Hall currents, Soret and Dufour number on MHD mixed convection flow over a vertical surface in porous media, and they found that the fluid temperature increases due to an increase in the thermal radiation. Also they found that the concentration decreases as the radiation parameter value is increased. Pal and Mondal [16] examined the effects of Soret Dufour, chemical reaction and thermal radiation on MHD non-Darcy unsteady mixed convective heat and mass transfer over a stretching sheet, and they concluded that the effect of thermal radiation is to increase temperature in the thermal boundary layer. The effects of thermal radiation and viscous dissipation on MHD heat and mass diffusion flow past an oscillating vertical plate embedded in a porous medium with variable surface conditions were studied by Kishore et al. [17]. Thermal radiation effects on MHD convective flow over a plate in a porous medium was studied by Karthikeyan et al. [18] by using perturbation technique, and it was observed that the increase in the radiation parameter implies the decrease in the boundary layer thickness and enhances the rate of heat transfer. Hossain and Samand [19] examined the heat and mass transfer of a MHD free convection flow along a stretching sheet with chemical reaction, thermal radiation and heat generation in the presence of magnetic field. They conclude that the concentration profiles increase as the values of the radiation parameter is increased. Recently, Hsiao [20] performed an analysis to study the combined effects mixed convection and thermal radiation in nanofluid with multimedia physical features.

Viscous dissipation plays an important role in changing the temperature distribution, just like an energy source, which affects the heat transfer rates considerably. In fact, the shear stresses can induce a considerable amount of heat generation. El-Aziz [21] investigated the mixed convection flow of a micropolar fluid from an unsteady stretching surface with viscous dissipation. He concluded that the viscous dissipation produces heat due to drag between the fluid particles and this extra heat causes an increase of the initial fluid temperature. This increase in the temperature causes an increase in the buoyant force. Kishore et al. [22] studied the influence of chemical reaction and viscous dissipation on unsteady MHD free convection flow past an exponentially accelerated vertical plate with variable surface conditions. They examined that the increase in the viscous dissipation enhanced the fluid temperature, also the rate of heat transfer fell with increasing the Eckert number. Singh and Singh [23] analyzed MHD flow with viscous dissipation and chemical reaction over a stretching porous plate in