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Numerical simulation of couple stress nanofluid flow in magneto-porous medium with thermal radiation and a chemical reaction

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ABSTRACT

We present a study of heat and mass transfer for a couple stress nanofluid flow in a magneto-porous medium with thermal radiation and heat generation. The flow is generated by a stretching surface and the temperature and concentration distributions are studied subject to nanoparticle Brownian motion and thermophoresis effects. The nonlinear model equations have been solved using a spectral quasi-linearization method. The solution method has been used in a limited number of studies in the resent past. Its general reliability for a wider range of problems remains to be determined. Thus in order to determine the accuracy of the solutions, and the convergence of the method, a qualitative presentation of residual errors for different parameters is given. Additionally, for some special flow cases, the current results have been compared with previously published work and found to be in good agreement. A limited parametric study showing the influence of the flow parameters on the fluid properties is given. The numerical analysis of the residual error of PDEs and convergence properties of the method are also discussed. The method is computationally fast and gives very accurate results after only a few iterations using very few grid points in the numerical discretization process. The aim of this manuscript is to pay more attention of residual error analysis with heat and fluid flow on couple stress nanofluids to improve the system performance. Also the fluid temperature in the boundary layer region rise significantly for increasing the values of thermophoresis and Brownian motion parameter. The results show that wall shear stress increases by increasing couple stress parameter.

1. Introduction

Heat and mass transfer processes have been focused of extensive investigation for many decades due to the importance of these processes of physiological flows such as urine transport from kidneys to the bladder and the circulation of blood in small blood vessels. The theory of couple stress fluids, first introduced by Stokes [1] has been widely studied by researchers [2,3]. Couple stresses appear in fluids with very large molecules such as in synovial fluids, for example, Walicki and Walicka

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[4] modelled synovial fluids in human joints as couple stress fluids. Examples of studies of the flow of couple stress fluids include Hiremath and Patil [5] who investigated the oscillatory flow of a couple stress fluid through a porous medium while the melting heat transfer in the boundary layer flow of a couple stress fluid over a stretching surface was investigated by Hayat et al. [6].

Nanofluids are recent fluids that offer the promise of significantly enhanced thermophysical properties. Typical base liquids include water, oil or ethylene glycol. The addition of nanoparticles to the base liquids greatly enhances the thermal characteristics of the base liquid. Nanofluids are used in various industrial and technological processes such as in the cooling of electronic devices, transformer cooling, heat exchangers, biomedicine and many other uses. Couple stress nanofluids are useful in MHD power generators, for the removal of blockages in arteries, hyperthermia, cancer tumor treatment, magnetic resonance imaging, etc. Couple stress nanofluid flow occurs in industrial and technological processes such as in hot rolling, wire drawing, glass fiber and paper production, extrusion of polymer fluids and the solidification of liquid crystals. Further recent investigations on nanofluid flows can be quoted through the studies [7,8].

Introducing a magnetic field to the flow of a conducting fluid generally alters the flow field. In general, the magnetic field has a stabilizing effect on the instability, but there are few exceptions. The use of magnetic field to influence heat generation processes in electrically conducting fluids has important engineering applications. For example, in many metallurgical processes such as the drawing of continuous filaments through quiescent fluids, and the annealing and tinning of copper wires, the properties of the end product depends on the rate of cooling. Pal and Mondal [9] studied the effect of MHD and variable viscosity on non-Darcy mixed convective heat transfer over a stretching sheet embedded in a porous medium with non-uniform heat source/sink. Ali et al. [10] analyzed the MHD flow and heat transfer of a couple stress fluid over an oscillatory stretching sheet with heat source/sink in porous medium. Ramesh and Dekavar [11] studied the magnetohydrodynamic peristaltic flow of a couple stress fluid through a homogenous porous media in an asymmetric channel with heat transfer. The flow of a couple stress fluid with variable thermal conductivity was studied by Asad et al. [12]. The MHD flow of an incompressible fluid over a moving surface with a convective boundary condition was studied by Makinde [13]. Sreenadh et al. [14] investigated the flow of a couple stress fluid in a vertical porous layer by applying perturbation method.

Thermal radiation effect plays a significant role in controlling heat transfer processes in polymer processing industries. Additionally, the effect of thermal radiation on flow and heat transfer processes is of major importance in the design of many advanced energy convection systems which operate at high temperatures. Thermal radiation in these systems is usually the result of emission from hot walls and the working fluid. Thermal radiation becomes important when the difference between the surface and the ambient temperature is large. Thus an understanding of radiation heat transfer in a system may assist in achieving productswith desired characteristics. The influence of thermal radiation on hydromagnetic Darcy-Forchheimer mixed convection flow past a stretching sheet embedded in a porous medium was examined by, among others, Pal and Mondal [15].

There is a large number of practical situations in which convection is driven by internal heat sources. This occurs for instance in nuclear heat cores, nuclear disposals, oil extraction and crystal growth. Double diffusive convection in a couple stress fluid with internal heat source was studied by Gaikwad and Kouser [16]. Chamka [17] found solutions for hydromagnetic heat and mass transfer from an inclined plate with internal heat generation or absorption. Hill [18] analyzed double diffusive convection in a porous medium with a concentration based internal heat source. The onset of convection in a porous medium with internal heat generation was investigated by Gasser and Kazimi [19]. Capone et al. [20] analyzed double diffusive penetrative convection with internal heating in an anisotropic porous layer with through flow.

Nagaraju et al. [21] analyzed the effects of thermal radiation, a chemical reaction and heat generation in a nanofluid. Rehman et al. [22] investigated porosity and nano-concentration effects on the stagnation flow of a couple stress fluid over an exponentially stretching surface. Das [23] studied the effects of thermal radiation and chemical reaction on unsteady MHD free convection heat and mass transfer flow of a micropolar fluid past a vertical porous plate in a rotating frame of reference, assuming that the plate is embedded in a uniform porous medium and oscillates in time with a constant frequency in the presence of a transverse magnetic field. Srinivasacharya and Mendu [24] analyzed the flow and heat and mass transfer characteristics of the free convection on a vertical plate with uniform wall temperature and concentration in a micropolar fluid in the presence of a first-order chemical reaction and radiation. Jain et al. [25] studied the effects of radiation and couple stress parameters on unsteady magnetopolar free convection flow with mass transfer and thermal radiation in slip flow regime. The effect of rotation on the onset of double diffusive convection in a Darcy porous medium saturated with a couple stress fluid was studied by Malashetty et al. [26]. The effect of rotation on the onset of double diffusive convection in a horizontal anisotropic porous layer was studied by Malashetty and Heera [27]. Convective instability in either a couple stress fluid layer or couple stress fluid-saturated porous layer heated from below has been investigated in the recent past including the effects of an additional diffusing component (i.e., solute concentration) and external constraints such as magnetic field and /or rotation. Sunil et al. [28] investigated the effect of a magnetic field and rotation on a layer of couple stress fluid heated from below in a porous medium. Sharma and Sharma [29] have investigated the effect of suspended particles on electrically conducting couple stress fluid heated uniformly from below under the influence of uniform rotation and magnetic field.

In this paper, we present a study of the flow of a couple stress nanofluid over a stretching sheet in a magneto-porous medium with thermal radiation and chemical reaction. The model equations are solved using a method that combines the Chebyshev spectral collocation, bivariate Lagrange interpolation polynomials together with spectral quasi-linearization method (SQLM) is used. Residual error estimation is presented to show the high accuracy and fast convergence of the