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Nonlinear thermal radiation in three-dimensional flow of Jeffrey nanofluid: A model for solar energy

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ABSTRACT

This article explores the characteristics of thermophoresis and Brownian motion in magnetohydrodynamic three-dimensional flow of nano Jeffrey fluid. Flow analysis is modeled in the presence of thermal radiation. The resulting stretched flow problems have been solved for the velocity, temperature and concentration. The constructed expressions depend upon ratio of relaxation to retardation times, Deborah number, magnetic parameter, ratio of stretching rates, Lewis number, Prandtl number, radiation parameter, thermophoresis and Brownian motion parameters. Plots are presented and analyzed specifically for the temperature and nanoparticle concentration profiles. Numerical computations are performed for local Nusselt and Sherwood numbers. Impact reflecting the contributions of various embedded on the local Nusselt and Sherwood numbers is point out. It is observed that temperature and nanoparticle concentration profiles are decreased with an increase in Deborah number. An increase in thermophoresis parameter shows rise to the temperature and nanoparticle concentration fields. It is also seen that temperature and nanoparticle concentration profiles are quite opposite when Brownian motion parameter is increased.

1. Introduction

Human society at present has a very serious issue of sustainable energy generation. Such challenge in fact arises because of fast development of human society globally during the past few decades. No doubt such fast development offered shortage of global energy and serious environmental pollution. Researchers in field from all the countries are looking for new energy sources and technologies to meet such requirement. Solar energy in this situation offers one of the best solutions through minimal environmental impact. Solar energy comes direct from the sun and can be turned into heat or electricity. Solar energy can produce energy for billions of years. Solar energy that reaches the earth is around 4×1015 MW. Solar energy is 2000 times larger than the global energy consumption. Hence much more attention is now attracted by the applications of solar power technologies and solar power energy. Power solar collectors could benefit from the potential efficiency improvements that arise from using a nanofluid as a working fluid. Nanomaterial is introduced as a new energy material because its particle size is likely or smaller that the coherent or de Broglie waves. Incident radiations are strongly absorbed by the nanoparticles. The applications of nanofluids in solar power systems depend on the radiative motion of nanoparticles that opens the new study area for scientists and engineers.

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A mixture of nanoparticle and base fluid is known as nanofluid. Nanofluid is a new category of heat transfer fluids. To meet the cooling rate requirements in industry, the thermal performance of ordinary heat transfer fluids is not suitable. Nanoparticles are inserted to enhance the thermal characteristics of base liquids. Nanofluids involve the nanosized particles. Novel properties of nanofluids make them quite useful in many engineering and industrial applications include hybrid-power engines, fuel cells, microelectronics, pharmaceutical processes, etc. Nanofluids are further utilized in heat exchanger processes like automotives, refrigeration, process industry and chemical industry. In addition the magneto nanofluids have great importance in the processes of targeted drug release, elimination of tumors with hyperthermia, asthma treatment, synergistic effects in immunology, cancer therapy, construction of power generators, etc. Choi [1] introduced the term nanofluid and showed that the insertion of nanoparticles in base fluid is best candidate to enhance the thermal performance of base liquids. Buongiorno [2] presented a mathematical model to study the thermal characteristics of nanofluids. Later on, Makinde and Aziz [3] developed a model to examine the boundary layer flow of viscous fluid over a stretching surface with convective boundary condition. They addressed that the convective boundary condition is more realistic than the constant surface temperature or heat flux conditions. Influence of thermophoresis and Brownian motion in stagnation point flow of viscous fluid towards a stretching sheet was discussed by Mustafa et al. [4]. Turkyilmazoglu [5] investigated the analytical solutions of heat and mass transfer analysis in MHD nanofluids flow with slip conditions. Rashidi et al. [6] carried out a study to simulate the axisymmetric mixed convection nanofluid flow past a cylinder. Effects of thermal and concentration stratifications in mixed convection flow of viscous fluid were discussed by Ibrahim and Makinde [7]. Turkyilmazoglu and Pop [8] examined the unsteady natural convection flow of nanofluid in the presence of thermal radiation over a vertical flat surface. Heat and mass transfer characteristics are explored here. Natural convection flow of CuO–water nanofluid in a cavity with sinusoidal wall was addressed by Sheikholeslami et al. [9]. In another investigation, Sheikholeslami et al. [10] presented the numerical solution of magnetohydrodynamic Al_2O_3–water nanofluid in a semi-annulus. Analysis of second law of thermodynamics on MHD flow of nanofluid induced by a rotating disc was reported by Rashidi et al. [11]. Influence of nanoparticles in Jeffrey–Hamel flow was addressed by Moradi et al. [12]. Turkyilmazoglu [13] investigated the unsteady convection flow of nanofluids with prescribed surface temperature and prescribed surface heat flux. Here the author discussed the influence of radiative heat transfer. Buoyancy driven mixed convection stagnation point flow with convective heat transfer over a stretching/shrinking surface was numerically studied by Makinde et al. [14]. Sheikholeslami et al. [15–18] investigated the magnetic field effect in flow of nanofluid under various aspects.

The boundary layer flow of non-Newtonian fluid induced by a stretching surface is hot topic of research now a days. Such flows appear in boundary layer along a liquid film condensation process, annealing and thinning of copper wires, aerodynamic extrusion of plastic films, cooling of an infinite metallic plate in a cooling bath, polymer filament or sheet extruded continuously from a dye and many others. Further the boundary layer flow of non-Newtonian fluid combined with heat and mass transfer are of great interest in petroleum industry and engineering applications. Examples of such applications include damage of crops due to freezing, desalination, compact heat exchangers, refrigeration and air conditioning, chemical processing equipment, solid matrix heat exchangers, solar power collectors, etc. Hayat and Alsaedi [19] considered the MHD flow of Oldroyd-B fluid with heat and mass transfer effects with radiation, Joule heating and thermophoresis. Galanis and Rashidi [20] discussed the entropy generation analysis in non-Newtonian fluid combined with heat and mass transfer. Mixed convection flow of viscoelastic fluid with heat and mass transfer effects induced by a permeable stretching surface was addressed by Turkyilmazoglu [21]. Shehzad et al. [22] studied the heat and mass transfer analysis combined with Soret and Dufour effects in boundary layer flow of Jeffrey fluid with convective thermal condition. Effects of heat and mass transfer in unsteady flow of viscoelastic fluid over a stretching surface were examined by Alsaadi et al. [23]. Olajuwon and Oyelakin [24] examined the mixed convective heat and mass transfer in power-law non-Newtonian fluid over a moving vertical plate.

The present attempt is made to present a mathematical model of three-dimensional flow of Jeffrey nanofluid over a stretching surface. Thermophoresis and Brownian motion effects are present. Mathematical model is prepared in presence of thermal radiation utilized in presence of thermal radiation. Similarity variables are employed to convert the nonlinear partial differential equations into ordinary differential equations. Homotopy analysis method (HAM) [25–32] is adopted to obtain the solution expressions of velocity, temperature and concentration. Convergence analysis of obtained solutions is made graphically and numerically. Graphs of temperature and concentration are presented and analyzed for various embeded parameters. Local Nusselt and Sherwood numbers are examined through numerical data. It is pertinent to mention that homotopy analysis method has great freedom to choose the auxiliary linear operators and initial guesses like other methods. For example, Sheikholeslami and Ganji [33] investigated the three-dimensional flow in a rotating system by employing Runge–Kutta fourth order numerical scheme. Analytical investigation of MHD Jeffrey–Hamel flow with nanoparticles via Adomian decomposition method is discussed by Sheikholeslami et al. [34]. Sheikholeslami and Ganji [35] utilized the homotopy perturbation method to investigate the heat transfer in Cu–water nanofluid. In another study, Sheikholeslami and Ganji [36] used homotopy asymptotic method to explore the properties of Magnetohydrodynamic viscous fluid flow in a channel with nanoparticles.

2. Problems formulation

We consider three-dimensional flow of an incompressible Jeffrey fluid with heat and mass transfer. A uniform magnetic field of strength B_0 is applied in the z-direction. An induced magnetic field is neglected due to small magnetic Reynolds number. Thermophoresis and Brownian motion effects are present. Thermal radiation is taken into account via Rosseland's approximation. The extra stress tensor for a Jeffrey fluid can be expressed as