Effects of thermophoresis and thermal radiation on MHD mixed convective heat and mass transfer flow

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Abstract An analysis is presented to investigate the combined effects of thermophoresis and thermal radiation on MHD mixed convective heat and mass transfer flow of an incompressible, electrically conducting second grade fluid past a semi-infinite stretching sheet in the presence of viscous dissipation and Joule heating. The governing boundary layer equations are written into a dimensionless form by similarity transformations. The transformed non-linear ordinary differential equations are solved numerically using symbolic software MATHEMATICA. Favorable comparison with previously published work is performed. Numerical results for dimensionless velocity, temperature, concentration as well as the skin friction coefficient, Nusselt number and Sherwood number are presented through graphs and tables for pertinent parameters to show interesting aspects of the solution.

Keywords Thermal radiation · Viscous dissipation · Joule heating · Second grade fluid · Thermophoresis

Mathematics Subject Classification 76W05

1 Introduction

Boundary layer behavior of non-Newtonian fluids over a stretching surface is a topic of current interest because of its engineering and industrial applications; for instance processing of polymers, oil recovery, food processing, paper making, etc. Fluids of non-Newtonian characteristics which are electrically conducting can be opted as a cooling liquids as their flow can be controlled by external magnetic field which regulates heat transfer to some extent. Heat and mass transfer of non-Newtonian fluids is also very important in many engineering applications, such as metallurgical process, polymer extrusion process involves cooling of a molten liquid being stretched into a cooling system, glass blowing, crystal growing and so on.
Extensive research on boundary layer flow over a stretching surface has been undertaken since pioneering work of Sakiadis [1]. Crane [2] is the first to consider the boundary layer behavior over an extensible surface where he assumes the velocity of the surface to vary linearly with the distance from the slit. Various aspects of the problem have been investigated by many authors [3–10]. Hsiao [11] considered the heat transfer on a stretching sheet cooled or heated by a high or low Prandtl number for second grade visco-elastic fluid. However, the effect of thermal radiation on the flow and heat transfer have not been provided in the most investigations. The effect of radiation on MHD flow and heat transfer problem have become more important industrially. At high operating temperature, radiation effect can be quite significant. Many process in engineering areas occur at high temperature and a knowledge of radiation heat transfer becomes very important for design of reliable equipment, nuclear plants, gas turbines and various propulsion devices or aircraft, missiles, satellites and space vehicles. Based on these applications, Cogley et al. [12] showed that in the optically thin limit, the fluid does not absorb its own emitted radiation but the fluid does absorb radiation emitted by the boundaries. Makinde [13] examined the transient free convection interaction with thermal radiation of an absorbing emitting fluid along moving vertical permeable plate. Ibrahim et al. [14] discussed the case of mixed convection flow of a micropolar fluid past a semi infinite, steady moving porous plate with varying suction velocity normal to the plate in presence of thermal radiation and viscous dissipation. Hayat et al. [15] studied a two dimensional mixed convection boundary layer MHD stagnation point flow through a porous medium bounded by a stretching vertical plate with thermal radiation. Das [16] discussed the effect of thermal radiation on MHD slip flow over a flat plate with variable fluid properties. Recently Olajuwon [17] examined convection heat and mass transfer in a hydromagnetic flow of a second grade fluid in the presence of thermal radiation and thermal diffusion.

Thermophoresis is a phenomenon, which causes small particles to be driven away from a hot surface and towards a cold one. Small particles, such as dust, when suspended in a gas with a temperature gradient, experience a force in the direction to the temperature gradient. The velocity acquired by the particles is termed as thermophoretic velocity and the force experienced by the suspended particles due to the temperature gradient is termed as thermophoretic force. The magnitudes of thermophoretic velocity and thermophoretic force are proportional to the temperature gradient and depend on thermal conductivity of aerosol particles, the carrier gas, heat capacity of the gas, thermophoretic coefficient and Knudsen number. Due to thermophoresis, small micron sized particles are deposited on cold surfaces. In this process, the repulsion of particles from hot objects also takes place and a particle-free layer is observed around hot bodies (see Goldsmith and May [18]). This phenomenon has many practical applications in removing small particles from gas particle trajectories from combustion devices, and studding the particulate material deposition turbine blades.

Goren [19] investigated the effect of thermophoresis on laminar flow over a horizontal flat plate which has been extended to a natural convection with variable properties by Jayaraj et al. [20]. Selim et al. [21] studied the effect of surface mass flux on mixed convection flow past a heated vertical flat plate with thermophoresis. Chamkha and Pop [22] considered the effect of thermophoresis particle deposition in free convection boundary layer from a vertical plate embedded in a porous medium. Chamkha et al. [23] discussed the effect of thermophoresis of aerosol particles in laminar boundary layer on a vertical plate. Kandasamy et al. [24] examined the effects of variable viscosity and thermophoresis on MHD mixed convective heat and mass transfer past a porous wedge. Recently, Zueco et al. [25] investigated the effect of thermophoresis particle deposition and of the thermal conductivity in a porous plate with dissipative heat and mass transfer.