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Effects of homogeneous and heterogeneous reactions and melting heat in the viscoelastic fluid flow

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ABSTRACT

This communication investigates the impact of homogeneous and heterogeneous reactions in the boundary layer flow of viscoelastic fluid. Flow is caused by a stretching cylinder with melting heat transfer. Incompressible fluid is electrically conducting through an inclined magnetic field. Mathematical problems for velocity, temperature and concentration are formulated using boundary layer theory. Outcoming differential systems are computed for the convergent series solutions. Impacts of different pertinent parameters on the velocity, temperature and concentration are explored. Skin friction coefficient and Nusselt number are analyzed through numerical values.

1. Introduction

The analysis of heat transfer accompanied with stretching surfaces has gained the interest of scientists and researchers due to their immense applications in various areas of industrial, manufacturing, biomedical and engineering phenomena. Heat treatment of moving surfaces into a cooling medium has significant role since characteristics of the output products greatly depend on the process of heat treatment. Metals are heated and cooled in a specific order during the heat treatment process in order to keep the metal away from molten state. This process is essential to make a metal harder, stronger and more resistant. Such process is also used for a more soften and ductile metal. Specific applications consist of drawing of copper wires, polymer extrusion, continuous stretching of plastic films and artificial fibers, hot rolling, glass-fiber, metal extrusion, metal spinning etc. Zheng et al. [1] investigated heat transfer in pseudo-plastic non-Newtonian fluids with variable thermal conductivity. Turkyilmazoglu [2] studied an analytical solution of MHD viscoelastic fluid and mixed convection heat transfer by a permeable stretching surface. Abbasbandy et al. [3] presented series solution for unsteady boundary layer equations in viscoelastic fluid. Farooq et al. [4] addressed magnetohydrodynamics flow of Jeffrey fluid with Newtonian heating. Hayat et al. [5] presented homogeneous–heterogeneous reactions in the stagnation point flow of carbon nanotubes with Newtonian heating characteristics. Farooq et al. [6] analyzed the characteristics of Newtonian heating with MHD three-dimensional flow of couple stress fluid. Sheikholeslami et al. [7] discussed the heat transfer characteristics of magnetohydrodynamic nanofluid flow with viscous dissipation. Kandelousi et al. [8] presented simulation of nanofluid flow and heat transfer for KKL correlaton in permeable channel. Sheikholeslami et al. [9] used two phase model to analyze the impact of variable MHD and force convection in nanofluid. Sheikholesami et al. [10] also addressed effect of non-uniform magnetic field on forced convection heat transfer of Fe3O4-water nanofluid. Ellahi et al. [11] investigated three dimensional mesoscopic simulation of magnetic field influence on natural convection of nanofluid. Sheikholeslami et al. [12] further discussed characteristics of MHD nanofluid flow and heat transfer in an annulus.

Recently scientists and engineers are devoted to have interest in developing some different catalytic processes working at high temperature. Such processes engage both homogeneous and heterogeneous reactions together. A number of reactions have the capacity to proceed gradually or not at the moment, excluding in the existence of a catalyst. The interaction between the homogeneous and heterogeneous reactions is very composite linking the construction and utilization of reactant species both within the fluid and on the catalyst surface at different rates. These reactions appear in combustion, catalysis, biochemical systems and industrial processes. Merkin [13] considered boundary corresponding layer flow of isothermal model for homogeneous heterogeneous reactions. Hayat et al. [14] analyzed magnetohydrodynamic stretched flow of Maxwell fluid with homogeneous/heterogeneous chemical reactions. Shaw et al. [15] investigated the properties of homogeneous–heterogeneous reactions in the flow of micropolar fluid by a porous stretching/shrinking sheet effect in a porous medium. Kameswaran et al. [16] examined homogeneous–heterogeneous

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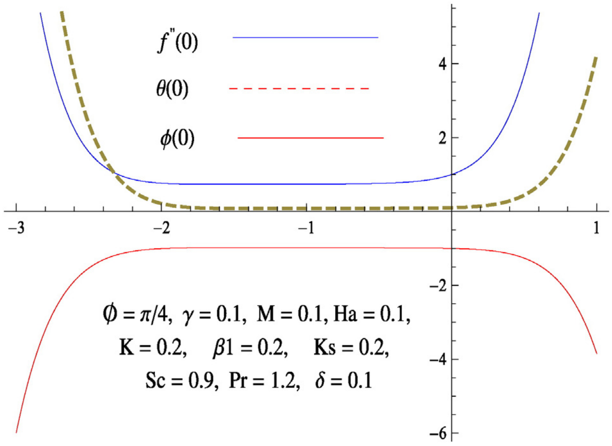

Fig. 1. $\hbar-$*curves.*

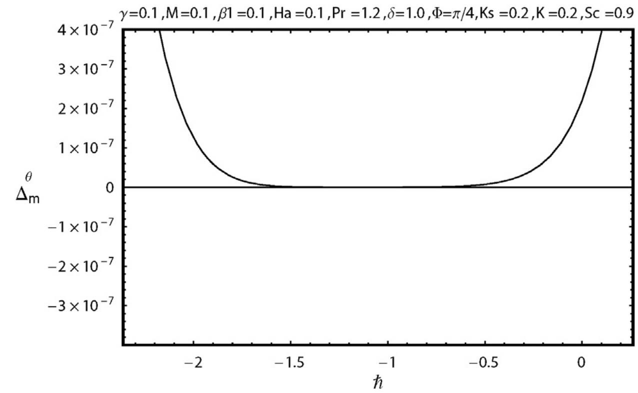

Fig. 3. $\hbar-$*curve* for residual error Δ_m^θ.

reactions in boundary layer flow of nonofluid past a permeable stretching sheet. Hayat et al. [17] discussed homogeneous–heterogeneous reactions effect on peristalsis in a curve channel.

Melting heat phenomenon has received the attention of the researchers and scientists due its widespread applications in innovative technological and industrial processes. Recently scientists have given full attention to develop more sustainable, efficient and low cost energy storage technologies. Such technologies are interconnected with solar energy, waste heat recovery and plants of heat and power. Mainly three methods are used for the storage of energy i.e., sensible heat energy storage latent heat energy storage and chemical thermal energy storage. However an economically more suitable and efficient way of energy storage is the latent heat by changing the phase of materials. Thermal energy is stored in a material through latent heat by melting and again recovered by freezing it. Such applications involve freezing of soil around the heat exchanger coils of a ground based pump, magma solidification, the freeze treatment of sewage, the preparation of semiconductor material, the casting and welding of a manufacturing process. Rahman et al. [18] examined melting phenomenon in magnetohydrodynamic (MHD) steady flow and heat transfer by a moving surface with thermal radiation. Melting heat phenomenon of ice slab placed in the stream of hot air is studied first time by Robert [19]. Das [20] presented MHD boundary layer flow over a surface with radiation and melting effects. Hayat et al. [21] analyzed melting heat transfer in boundary layer flow of viscoelastic fluid with Soret and Dufour effects. Farooq et al. [22] studied melting heat transfer in the stagnation point flow of Powell–Eyring fluid. Yacob et al. [23] discussed melting heat transfer in boundary layer stagnation-point flow of micropolar fluid toward a stretching/shrinking sheet.

The main objective here is to disclose the effects of homogeneous–heterogeneous reactions and melting heat phenomenon in the magnetohydrodynamic second grade fluid flow. Heat transfer is tackled with heat generation/absorption. Both species are considered with equal diffusion coefficient. Homotopy analysis approach [24–32] is utilized to achieve the convergent series solutions of momentum, energy and concentration equations. Skin friction coefficient and Nusselt number corresponding to various physical parameters are calculated and analyzed numerically.

2. Mathematical formulation

Consider the steady two-dimensional and incompressible MHD boundary layer flow of viscoelastic fluid by a stretching cylinder. Effects of melting heat and homogeneous–heterogeneous reactions are considered. We assume that the melting at steady rate at constant property with homogeneous–heterogeneous reactions is considered. We assume that $T_m < T_\infty$ where T_∞ denotes the ambient temperature and T_m the temperature of the melting surface. Fluid is electrically conducting in the presence of an inclined magnetic field. Inclination angle is denoted by Φ. Induced magnetic effect is negligible due to small magnetic Reynolds number. Electric field impact is also absent. The heat produced during the irreversible chemical reaction is ignored. Merkin [13–17] first time analyzed the model for isothermal homogeneous–heterogeneous

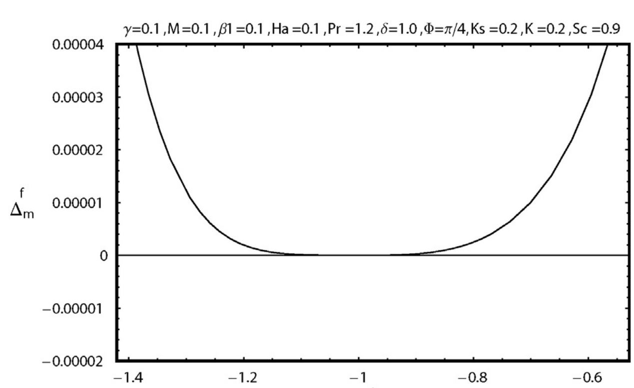

Fig. 2. $\hbar-$*curve* for residual error Δ_m^f.

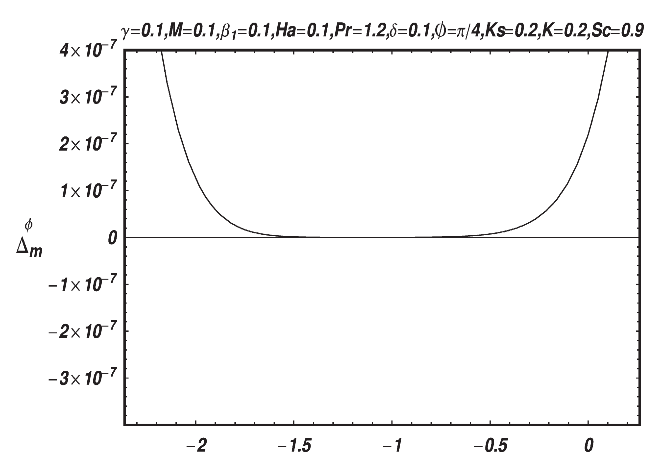

Fig. 4. $\hbar-$*curve* for residual error Δ_m^ϕ.