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Numerical simulation for aspects of homogeneous and heterogeneous reactions in forced convection flow of nanofluid

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ABSTRACT

Mixed convection stagnation point flow of nanofluid by a vertical permeable circular cylinder has been addressed. Water is treated as ordinary liquid while nanoparticles include aluminium oxide, copper and titanium dioxide. Homogeneous-heterogeneous reactions are considered. The nonlinear higher order expressions are changed into first ordinary differential equations and then solved by built-in-Shooting method in mathematica. The results of velocity, temperature, concentration, skin friction and local Nusselt number are discussed. Our results demonstrate that surface drag force and heat transfer rate are enhanced linearly for higher estimation of curvature parameter. Further surface drag force decays for aluminium oxide and it enhances for copper nanoparticle. Heat transfer rate enhances with increasing all three types of nanoparticles. In addition, the lowest heat transfer rate is obtained in case of titanium dioxide when compared with copper and aluminium oxide.

Introduction

Many industrial liquids have low thermal conductivity which limits the quality of final product during engineering procedure. Pioneer concept of nanomaterial with improved thermal conductivity was given by Choi [1]. Nanotechnology has significance in atomic reactors, chemical process, energy process, mechanical cooling, indicative tests, extraction of geothermal force, disease treatment, heat exchangers and some applications in micro scale fluidic. Convective transport in nanoliquids subject to thermophoresis and Brownian effects is explored by Boungiorno [2]. Effect of nanomaterials on natural convective flow past a vertical surface is examined by Kuznetsov and Nield [3]. Later on the same problem is discussed by Nield and Kuznetsov [4] for a porous space. MHD natural convection carbon nanotubes flow has been studied by Ellahi et al. [5]. Nanofluid flow of forced convection with magnetic field utilizing LBM is explored by Sheikholeslami et al. [6]. Convective heat transfer characteristics of Al_2O_3 nanomaterials submerged in water is studied by Hwang et al. [7]. Kumaresan et al. [8] discuused convective heat transfer characteristics of secondary refrigerant based nanoliquids. Flow of nanoliquid in a porous channel is addressed by Hatami et al. [9]. Farooq et al. [10] analyzed MHD stagnation point flow of Jeffrey nanomaterial in the presence of radiation. Mabood et al. [11] addressed mixed convection unsteady flow of nanofluid with viscous dissipation. Convective flow of Cu-water nanomaterial by a rotating cone using is studied by Dinarvand and Pop [12]. Few more recent studies about flows of nanofluids can be visualized through the attempts [13–18].

Heat transfer in flow over a stretchable surface has widespread applications. Due to tremendous applications in engineering and sciences, a large amount of work is focussed at present in this area, drawing of plastic sheets, fibres glass, paper production, metal spinning, fibre and wire coating, food stuff processing, continuous casting, exchangers and chemical processing equipment. All procedures of coating involve a smooth glossy surface to fulfill the necessities for appearance, transparency, strength and low fraction. Crane [19] initiated flow of viscous liquid by a stretched surface. MHD stagnation point flow of rate type nanofluid with thermophoresis is investigated by Bai et al. [20]. Heat transfer in flow of micropolar liquid over a porous stretching surface is examined by Turkyilmazoglu [21]. Melting heat transfer and homogeneous heterogeneous reactions in MHD viscous liquid flow by a stretchable surface is explored by Hayat et al. [22]. Magnetohydrodynamic nanofluid flow past a porous plate with radiation, chemical reaction and rotation is considered by Reddya et al. [23]. Consequences of convective boundary conditions and chemical reaction on flow due to a plate are considered by Rout et al. [24]. Application of non-Fourier heat flux in flow of Jeffrey liquid with temperature dependent thermal conductivity is studied by Hayat

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et al. [25]. Hayat et al. [26] also investigated chemically reactive flow and non-Fourier heat flux in flow by a stretching surface. Viscous dissipation in three dimensional flow of viscous nanoliquid is reported by Mahanthesh et al. [27]. Numerical simulation is performed in this work. Hayat et al. [28] examined flow of Burgers nanoliquid in presence of magnetohydrodynamics (MHD) and convective condition. Li et al. [29] discussed characteristics of non-Fourier heat conduction in MHD nanofluid flow by a stretched surface. Stretched flow of Oldroyd-B fluid with Cattaneo-Chrsitov heat flux is inspected by Hayat et al. [30].

Prime objective of this analysis is to analyze the impacts of thermal radiation and mixed convection in stagnation point flow of viscous nanofluid by a vertical permeable cylinder. Homogeneous-heterogeneous reactions are also accounted. Induced electric and magnetic fields are absent. Computations for strong nonlinear systems are presented after non-dimensionalization through built-in-Shooting method [31–35]. Graphical analysis for various influential variables is addressed in detail.

Formulation

We investigate the mixed convection stagnation point flow of an electrically conducting incompressible viscous nanofluid by a vertical permeable circular cylinder of radius a. We choose cylindrical coordinate system such that x is along the stretching cylinder and r normal to x. Here u and w are the velocity components in x and r directions (see Fig. 1). A magnetic field of strength B_0 is exerted along radial direction. We represent T_w as temperature of cylinder and T_∞ the ambient temperature. For the formation of compound $3B$ the fluid phase reaction is [22,26]:

$$A + 2B \rightarrow 3B, \quad rate = k_c a^* b^{*2},$$

$$A + B \rightarrow 3B, \quad rate = k_s a^* b^{*2}.$$

In above expressions A and B denote chemical species, a^* and b^* the concentrations and k_c and k_s the rate constants. Both reaction processes are isothermal. The subjected problems statements are

$$\frac{\partial(ru)}{\partial x} + \frac{\partial(rw)}{\partial r} = 0, \tag{1}$$

$$u\frac{\partial u}{\partial x} + w\frac{\partial u}{\partial r} = u_e\frac{du_e}{dx} + \nu_{nf}\left(\frac{\partial^2 u}{\partial r^2} + \frac{1}{r}\frac{\partial u}{\partial r}\right) + \frac{\sigma_{nf}B_0^2}{\rho_{nf}}(u_e - u) + \frac{\phi\rho_s\beta_s + (1-\phi)\rho_f\beta_f}{\rho_{nf}}g(T - T_\infty), \tag{2}$$

$$u\frac{\partial T}{\partial x} + w\frac{\partial T}{\partial r} = \alpha_{nf}\left(\frac{\partial^2 T}{\partial y^2} + \frac{1}{r}\frac{\partial T}{\partial r}\right), \tag{3}$$

$$u\frac{\partial a^*}{\partial x} + w\frac{\partial a^*}{\partial r} = D_A\left(\frac{\partial^2 a^*}{\partial r^2} + \frac{1}{r}\frac{\partial a^*}{\partial r}\right) - k_c a^* b^{*2}, \tag{4}$$

$$u\frac{\partial b^*}{\partial x} + w\frac{\partial b^*}{\partial r} = D_B\left(\frac{\partial^2 b^*}{\partial r^2} + \frac{1}{r}\frac{\partial b^*}{\partial r}\right) + k_c a^* b^{*2}. \tag{5}$$

with

$$u = u_w(x) = u_0\left(\frac{x}{l}\right), \quad w = V_w^*, \quad T = T_w(x) = T_\infty + \Delta T\left(\frac{x}{l}\right),$$
$$D_A\frac{\partial a^*}{\partial r} = k_s a^*, \quad D_B\frac{\partial b^*}{\partial r} = -k_s a^* \text{ at } r = a,$$
$$u \rightarrow u_e(x) = u_\infty\left(\frac{x}{l}\right), \quad T \rightarrow T_\infty, \quad a^* \rightarrow a_o, \quad b^* \rightarrow 0 \text{ when } r \rightarrow \infty. \tag{6}$$

In above equations u and w indicate the velocity components, u_e the free stream velocity, where $V_w^* < 0$ corresponds to suction and $V_w^* > 0$ for injection, u_w the stretching velocity, ν_{nf} the kinematic viscosity, T the temperature, T_∞ the ambient temperature, ρ_f the density of nanofluid, g the gravity acceleration, ϕ the nanoparticle volume friction, β the thermal expansion coefficient, a^* and b^* the concentrations, l the characteristics length, B_0 the uniform magnetic field, σ the electrical conductivity, D_A and D_B the diffusion species, a_0 the positive dimensional constant, k_s the heat transfer coefficient, β the coefficient of thermal expansion and α_{nf} thermal diffusivity. Their definitions are

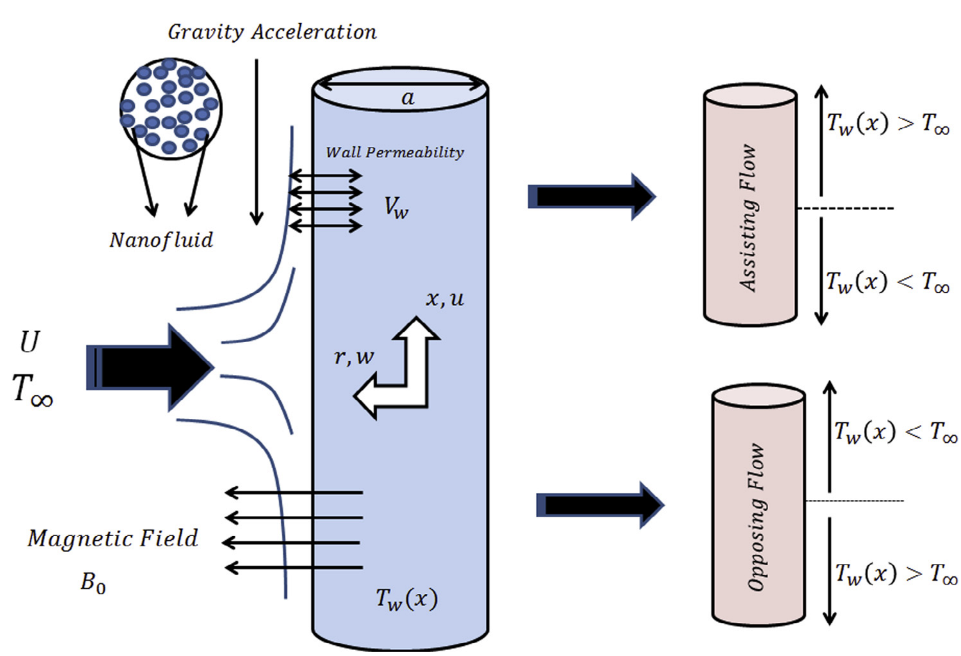

Fig. 1. Flow configuration.