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ORIGINAL ARTICLE

Natural convection and thermal radiation influence on nanofluid flow over a stretching cylinder in a porous medium with viscous dissipation

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Abstract The purpose of the present work is to examine the collective influence of thermal radiation and convection flow of Cu-water nanofluid due to a stretching cylinder in a porous medium along with viscous dissipation and slip boundary conditions. The governing non-linear ODEs and auxiliary boundary conditions those obtained by applying assisting similarity transformations have been handled numerically with shooting scheme through Runge-Kutta-integration procedure of fourth-fifth order. The non-dimensional velocity and temperature distribution are designed and also skin friction coefficient as well as heat transfer rate are tabulated for various values of relatable parameters. The results explain that Nusselt number depreciates with boost in radiation parameter, thermal slip parameter and Eckert number. Moreover, it is accelerated with increase in velocity slip parameter and natural convection parameter. The results are distinguished via published ones and excellent accord has been detected.

1. Introduction

The nanofluid is the amalgamation of suspensions of nano-size particles into the conventional fluids which was firstly pioneered by Choi [1]. The nanoparticles involved in this fluid are made of metals, carbides and oxides or carbon nanotubes, and conventional fluids take account of water, oil and ethylene glycol. The thermal conductivity of nanoparticles is larger than that of regular fluids, and due to this fact solid particles are used to enhance the thermal properties of base fluids. So the existence of nano solid particles in the conventional fluids heat transfer characteristics enhanced. There are several potential uses of nanofluids in heat transfer such as engine cooling, refrigerator, chiller, microelectronics, and fuel cells. In the analysis of heat transfer enhancement of nanofluid due to solid particles, there are two different approaches, one is single phase model, in which both solid particles and fluids are in thermal equilibrium and this model is simple and expedient for computation and next one is two-phase model, which deals

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with the role of solid particles and fluid in heat transfer process.

In the last few years, a lot of engineering function of convective flow in a porous medium such as building erection, solar collectors, ventilation procedure, temperature exchangers, and removal of heat from nuclear reactors. Wang [2] premeditated the steady flow of fluid over a stretching cylinder as of outer surface. The leading problem is a third order ODEs that leads to accurate similitude solutions of the Navier-Stokes equations. The combined effect of MHD and entropy generation flow over a stretching cylinder in the continuation of porous medium was deliberated by Butt et al. [3] they examined that as boost in magnetic parameter and permeability parameter thickness of momentum boundary layer diminishes. Ishak et al. [4] described suction/injection influence on steady flow of an incompressible fluid over a permeable stretching tube. They found that Reynolds number ascends as mounting in the numerical values of skin friction coefficient. Ashorynejad et al. [5] have considered the effect of magnetohydrodynamic flow over a stretching tube within nanofluid. They found that on escalating the values of flow rate both magnetic parameter and Reynolds number are augmented. Ahmed et al. [6] premeditated the joint influence of thermal conductivity, dynamic viscosity and heat source/sink in the existence of stretching permeable tube in nanofluid. Majeed et al. [7] considered the simultaneous impact of partial slip and heat transfer on steady non-Newtonian Casson fluid flow outside of stretching tube with arranged heat flux. They analyzed that as increase in Casson fluid parameter, the heat transfer rate diminishes. Hayat et al. [8] have discussed magnetohydrodynamic third grade fluid flow due to a stretching cylinder. They found that radial velocity decreases on diminishing Reynolds number. The impact of mixed convection steady flow on stretching tube has been proposed by Wang [9]. Si et al. [10] considered the heat transfer influence on unsteady viscous flow over a stretching porous tube. Wang and Ng [11] inspected viscous fluid flow outside of stretching cylinder with slip. They found that on enhancing the values of unsteady parameter temperature of nanoparticle rises. Ishak and Nazar [12] proposed the laminar and incompressible viscous fluid flow due to a stretching cylinder. Naramgari and Sulochana [13] presented the influence of flow and heat transfer on nanofluid flow over a stretching surface with MHD. Sk et al. [14] analyzed the combined influence of MHD and slip on permeable stretching surface in nanofluid. An assortment of studies to expect the influence of thermal radiation on nanofluid flow due to a stretching/shrinking sheet has been offered by [15–18]. Several efforts have been set to scrutinize the influence of natural convection during nanofluid flow under various conditions (see [19–24]). Ganga et al. [25] have discussed the viscous and ohmic dissipation effect on MHD flow over vertical plate with heat generation/absorption in a nanofluid. They established that Nusselt number reduces as diminished in Eckert number. Hayat et al. [26] have introduced the combined effect of Brownian motion and thermophoresis on viscoelastic nanofluid flow due to a stretching cylinder in the presence of mixed convection. The influences of thermal radiation on mixed convection flow over a different geometry were studied by [27–29]. Khan and Malik [30,31] examined the heat transfer flow of Sisko fluid over a stretching cylinder with convective boundary conditions. Very recently, analysis of heat transfer flow of Sisko fluid over a stretching cylinder is studied by [32,33]. Waqas et al. [34] have analyzed the boundary layer flow burger fluid over a stretching sheet with Cattaneo-Christov heat flux model. Again, Waqas et al. [35] investigated the influence MHD flow of micropolar fluid over a stretched surface with convective boundary conditions. Hayat et al. [36] have studied influence of source/sink on mixed convection flow in viscoelastic nanofluid due to a cylinder in the presence of variable thermal conductivity. Recently, influences of MHD flow of nanofluid over a different geometry were presented by [37–41]. The present work deals with the influence of natural convection, viscous dissipation, heat source/sink and thermal radiation on nanofluid steady flow over a stretching porous cylinder in the existence of slip boundary conditions. The numerical solution of the problem is acquired by employing shooting scheme based Runge-Kutta-Fehlberg-integration algorithm.

2. Mathematical formulation

Consider an axisymmetric, incompressible, steady, laminar flow of a nanofluid over a flat stretching porous pipe of radius b and (z, r) are taken as directions of axis toward horizontal and vertical of the cylinder as depicted in Fig. 1. It is presumed that surface temperature of the pipe is T_w and temperature far from the surface is T_∞ where $(T_w > T_\infty)$. The ohmic heating, magnetic field, suction/injection and Hall effect are neglected. The regular fluid (water) based nanofluid containing Cu (Copper) as a nanoparticle is considered. The physical properties of solid particles and regular fluid are mentioned in Table 1.

The primary equation of mass, momentum and energy for this model are articulated as follows (see in Refs. [4–6]):

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

$$\rho_{nf}\left(w\frac{\partial w}{\partial z} + u\frac{\partial w}{\partial r}\right) = \mu_{nf}\left(\frac{\partial^2 w}{\partial z^2} + \frac{1}{r}\frac{\partial w}{\partial r} - \frac{w}{k} + \frac{g(\rho\beta)_{nf}}{\mu_{nf}}(T - T_\infty)\right) \tag{2}$$

$$\rho_{nf}\left(w\frac{\partial u}{\partial z} + u\frac{\partial u}{\partial r}\right) = -\frac{\partial p}{\partial r} + \mu_{nf}\left(\frac{\partial^2 u}{\partial r^2} + \frac{1}{r}\frac{\partial u}{\partial r} - \frac{u}{r^2}\right) \tag{3}$$

$$(\rho C_p)_{nf}\left(w\frac{\partial T}{\partial z} + u\frac{\partial T}{\partial r}\right) = \left[k_{nf}\left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r}\right) + Q_0(T - T_\infty) - \frac{\partial q_r}{\partial r} + \mu_{nf}\left(\frac{\partial w}{\partial r}\right)^2\right] \tag{4}$$

The velocity and temperature coupled boundary conditions are [4–6] as follows:

$$\left.\begin{array}{l} u = U_w = 0,\ w = W_w + L\frac{\partial w}{\partial r},\ T = T_w + l\frac{\partial T}{\partial r} \text{ at } r = b, \\ u \to 0,\ T \to T_\infty \text{ as } r \to \infty \end{array}\right\} \tag{5}$$

where L and l are the velocity and thermal slip factor, and $(w,\ u)$ are the constituent of velocity along with $(z,\ r)$ axes respectively. The effective dynamic viscosity μ_{nf}, the effective density ρ_{nf}, the thermal diffusivity α_{nf}, the heat capacitance $(\rho C_p)_{nf}$, the thermal expansion coefficient (β_{nf}), and the thermal conductivity k_{nf} of the Cu-water nanofluid are defined as follows (see [5]):

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