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Original Research Paper

Framing the performance of induced magnetic field and entropy generation on Cu and TiO_2 nanoparticles by using Keller box scheme

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ABSTRACT

Aim of present communication is to inspect the impact of induced magnetic field and entropy generation on water based nanofluid. The thermal characteristic of nanofluids are explored using copper and titanium nanoparticles. The governing physical problem is modelled and by using scaling group of transformations. Obtained system of coupled nonlinear partial differential equations is converted into set of ordinary differential equations. These equations are solved numerically using implicit finite difference scheme. Entropy generation analysis is carried out to measure the disorder within the thermodynamical system. Effect of nanoparticles volume fraction on magnetic field components, skinfriction and local heat flux are computed and discussed in a physical manner. It is examined that magnetic field parameter reduces wall stress while it increases rate of heat transfer at surface. Local heat flux accelerate with increasing nanoparticles volume fraction. TiO_2 water based nanofluid showed better results for heat transfer than Cu water based nanofluid.

1. Introduction

Stagnation point flows are of great importance due to their valuable applications in many engineering processes for example cooling of nuclear reactors and electronic devices. The classical problem on stagnation point flow was examined by Hiemenz [1]. He inspected the persistent flow in vicinity of stagnation point. Later on, a number of studies were carried out to discuss stagnation point flow over stretching/shrinking surfaces under a variety of physical constraints. For instance Hayat et al. [2] investigated stagnation point flow of MHD Jeffrey fluid towards stretching sheet. Stagnation point flow of MHD Oldroyd-B fluid over a stretching surface influenced by mixed convection effects were analyzed by Sajid et al. [3]. They concluded that the magnitude of heat transfer at the wall is increased by an increase in the Archimedes number. More relevant studies can be interpreted in Refs. [4–7].

During manufacturing processes quality of product depend on thermal conductivity. Most of the fluids encountered have low thermal conductivity. Nanofluids are used to improve thermal conductivity. In this regard the pioneer concept has been coined by Choi and Eastman [8]. Nanofluids have wide range of applications in industry and science such as mechanical cooling, heat exchanger, targeted drug delivery, extraction of geothermal forces etc. Researchers deals with the characteristics of nanofluid mainly in two ways. Namely, single phase model and two phase model. In first approach the mixture of base fluid and nanoparticles are consider to be homogenous while in the latterly non-homogenous mixture of nanoparticles is taken into the account. Behavior of motile particles in nanofluid are discussed through Brownian diffusion and thermophoresis effects. Boungiorno [9] explored convective transport in nanofluids by incorporating Brownian diffusion and thermophoresis effects. Moreover, effect of nanoparticles on natural convective boundary layer flow past a vertical sheet was examined by Kuznetsov [10]. Later on, Nield [11] discussed same problem in porous medium. Boundary layer flow of nanofluid over a moving surface was investigated by Bachok et al. [12] in which they found that dual solution exists when the plate and free stream move in opposite direction. Hatami et al. [13] explored nanofluid flow and heat transfer in asymmetric porous channel with escalating or contracting wall. Studies on nanofluid for different geometries are conducted extensively by many investigators (see [14–16]). A considerable amount of research in composition of nanoparticles dispersed in base fluid has risen exponentially. Hwang et al. [17] studied convective heat transfer characteristics of water based Al_2O_3 nanofluid in fully developed laminar flow region. Their study revealed that improved thermal conductivity was achieved by mixing Al_2O_3 nanoparticles in water. Later, Sheik-

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zadeh et al. [18] explored natural convection of Cu–water nanofluid in a cavity with partially active side walls. Effects of nanoparticles migration and asymmetric heating on mixed convection of TiO_2-H_2O nanofluid inside a vertical microchannel was explained by Hadayati et al. [19].

Flow of fluid varies with magnetic effects. Induced magnetic field effects are dominant for small magnetic Reynolds number [20]. Induced magnetic field plays a vital role in certain areas such as flow beneath the earth surface, sunlight flares and sunspots, geothermal investigation of earth surface etc. Moreover, applications of induced magnetic field can be found in plasma [21]. Glauert [22] examined hydro magnetic boundary layer flow past a heated plate under the influence of uniform magnetic field. Impact of induced magnetic field on MHD generator was analyzed by Koshiba et al. [23]. Raptis and Soundalgekar [24] studied flow of an electrically directing fluid past a moving permeable plate with consistent heat flux and induced magnetic field. They discovered that induced magnetic field decreases with increasing magnetic field whereas it was directly proportional to mixed convection. Later on, Raptis and Masalas [25] considered magneto hydrodynamic flow past a plate with radiation. Influence of magnetic field on hydro magnetic free convection flow was exposed by Ghosh et al. [26]. Bég et al. [27] investigated electrically-conducting forced convection boundary layer flow with induced magnetic field effects. Bejan [28] carried out entropy generation analysis and concluded that the in a non isolated system disorder generates and entropy rise.$EG-Al_2O_3$ nanofluid in helical tube and laminar flow was analyzed for entropy effects by Falahat [29]. Mixed convection and entropy generation of nanofluid filled lid driven cavity under the influence of inclined magnetic fields was investigated by Selimefendigil et al. [30]. They concluded that entropy generation is a decreasing function of Hartmann number. Some notable recent articles are cited see Ref. [31,32].

By the inspiration of such wide applications of two phase model in biomechanics, so that in the present article study of induced magnetic field and stagnation point flow with nanoparticles of Cu and TiO_2 submerged in water is carried out. The governing system of nonlinear partial differential equations is reduced to a system of nonlinear ordinary differential equations whose numerical solutions are computed by means of finite difference algorithm. The main emphasis here is to analyze the effect of two different types of nanoparticles keeping the same based fluid. The novel results computed in this article are significant in academic, industrial research and discussion of stagnation point flow of Cu and TiO_2 water based nanofluid towards a stretching surface. Such flows are witness in many mechanical engineering problems such as coolants, MHD generators, geothermal processes and plasma theory. The accuracy of iterative scheme is set up to 6 decimal places. Graphs and tables are drawn to inspect impact of noteworthy physical parameters on fluid velocity, induced magnetic field and temperature profile. Moreover, in order to study influence of pertinent parameters at surface detailed analysis for skinfriction coefficient and Nusselt number is described.

2. Description of physical problem and governing equations

We consider steady two-dimensional stagnation point flow towards a linear stretching sheet at $y=0$ in the presence of induced magnetic field. Fluid occupies the region $y>0$. The free stream velocity is assumed to be $U_e(x)=ax$ and velocity of stretching sheet is $U_w(x)=cx$, where a and c are positive constants. Furthermore, we assumed that H is induced magnetic field vector with magnetic field at free stream $H_e(x)=H_0x$ inwhich H_0 is upstream uniform magnetic field at infinity. In addition we take H_1 and H_2 parallel and normal components of induced magnetic field H. At the surface, normal component H_2 vanishes whereas parallel component H_1 becomes H_0. Problem formulation is described in Fig. 1.

Governing boundary layer equations (see Ali et al. [4]) for electrically conducting viscous fluid can be expressed as

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0, \tag{1}$$

$$\frac{\partial H_1}{\partial x}+\frac{\partial H_2}{\partial y}=0, \tag{2}$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}-\frac{\mu}{4\pi\rho_f}\left(H_1\frac{\partial H_1}{\partial x}+H_2\frac{\partial H_1}{\partial y}\right) = \left(U_e\frac{dU_e}{dx}-\frac{\mu H_e}{4\pi\rho_f}\frac{dH_e}{dx}\right)+\left(\frac{\mu_{nf}}{\rho_{nf}}\right)\frac{\partial^2 u}{\partial y^2}, \tag{3}$$

$$u\frac{\partial H_1}{\partial x}+v\frac{\partial H_1}{\partial y}-H_1\frac{\partial u}{\partial x}-H_2\frac{\partial u}{\partial y}=\mu_e\frac{\partial^2 H_1}{\partial y^2}, \tag{4}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha_{nf}\frac{\partial^2 T}{\partial y^2}, \tag{5}$$

subject to boundary conditions

$$u=U_w=cx,\quad v=0,\quad T=T_w,\quad \frac{\partial H_1}{\partial y}=H_2=0,\quad \text{at}\quad y=0,$$
$$u\to U_e=ax,\quad T\to T_\infty,\quad H_1=H_e(x)\to H_0x,\quad \text{as}\quad y\to\infty, \tag{6}$$

where u, v, H_1 and H_2 are velocity and magnetic components along the $x-$ and $y-$directions respectively. ρ_{nf}, μ_{nf} and α_{nf} are density, dynamic viscosity and thermal diffusivity of nanofluid respectively. T is temperature of the fluid. Effective properties of nanofluid may be expressed in term of properties of the base fluid. Thermophysical properties of base fluids and nanoparticles are presented in Table 1. Moreover, Cu and TiO_2 nanoparticles and solid nanoparticles volume friction in the base fluid are expressed in Table 2. In which $(\rho c_p)_s$ is the volumetric heat capacity of solid nanoparticles, $(\rho c_p)_f, (\rho c_p)_{nf}$ are volumetric heat capacity of base fluid and nanofluid, respectively. ϕ is the particle volume fraction parameter of nanoparticles, ρ_f and μ_f are density and dynamic viscosity of base fluid, respectively. By using following similarity transformation

$$u=cxf'(\eta),\quad v=-\sqrt{c\nu_f}f(\eta),\ \eta=y\sqrt{\frac{c}{\nu_f}},$$

$$H_1=H_0xg'(\eta),\quad H_2=-\sqrt{c\nu_f}g(\eta),\quad \theta(\eta)=\frac{T-T_\infty}{T_w-T_\infty}. \tag{7}$$

Eqs. (1) and (2) are identically satisfied and other Eqs. (3)–(5) along with boundary condition (6) are reduced to the following nonlinear differential equations

$$A_1f'''-A_2\left\{f'^2-ff''-A^{*2}-\beta\left(g'^2-gg''-1\right)\right\}=0, \tag{8}$$

$$\lambda g'''+fg''-f''g=0, \tag{9}$$

$$A_3\theta''+PrA_4f\theta'=0, \tag{10}$$

subject to boundary conditions

$$f(\eta)=g(\eta)=0,\quad f'(\eta)=1,\quad g''(\eta)=0,\quad \theta(\eta)=1\text{at}\quad \eta=0,$$
$$f'(\eta)\to A^*,\quad g'(\eta)\to 1,\quad \theta(\eta)\to 0\quad \text{as}\ \eta\to\infty, \tag{11}$$

in which

$$A_1=\frac{1}{(1-\phi)^{2.5}},\quad A_2=(1-\phi)+\phi\left(\frac{\rho_s}{\rho_f}\right),$$

$$A_3=\frac{k_s+2k_f-2\phi(k_f-k_s)}{k_s+2k_f+2\phi(k_f-k_s)},\quad A_4=(1-\phi)+\phi\frac{(\rho c_p)_s}{(\rho c_p)_f},$$