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Mixed convective magnetohydrodynamic flow in a vertical channel filled with nanofluids

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ABSTRACT

The fully developed mixed convection flow in a vertical channel filled with nanofluids in the presence of a uniform transverse magnetic field has been studied. Closed form solutions for the fluid temperature, velocity and induced magnetic field are obtained for both the buoyancy-aided and -opposed flows. Three different water-based nanofluids containing copper, aluminium oxide and titanium dioxide are taken into consideration. Effects of the pertinent parameters on the nanofluid temperature, velocity, and induced magnetic field as well as the shear stress and the rate of heat transfer at the channel wall are shown in figures and tables followed by a quantitative discussion. It is found that the magnetic field tends to enhance the nanofluid velocity in the channel. The induced magnetic field vanishes in the cental region of the channel. The critical Rayleigh number at onset of instability of flow is strongly dependent on the volume fraction of nanoparticles and the magnetic field.

1. Introduction

Nanotechnology [1] has been broadly used in several industrial applications. It aims at manipulating the structure of the matter at the molecular level with the goal for innovation in virtually every industry and public endeavour including biological sciences, physical sciences, electronics cooling, transportation, the environment and national security. Low thermal conductivity of conventional heat transfer fluids such as water, oil, and ethylene glycol mixture is a primary limitation in enhancing the performance and the compactness of many engineering electronic devices. To overcome this drawback, there is a strong motivation to develop advanced heat transfer fluids with substantially higher conductivities to enhance thermal characteristics. Small particles (nanoparticles) stay suspended much longer than larger particles. If particles settle rapidly (microparticles), more particles need to be added to replace the settled particles, resulting in extra cost and degradation in the heat transfer enhancement. As such an innovative way in improving thermal conductivities of a fluid is to suspend metallic nanoparticles within it. The resulting mixture referred to as a nanofluid possesses a substantially larger thermal conductivity compared to that of traditional fluids. Nanofluids demonstrate anomalously high thermal conductivity, significant change in properties such as viscosity and specific heat in comparison to the base fluid, features which have attracted many researchers to perform in engineering applications. The popularity of nanofluids can be gauged from the researches done by scientists for its frequent applications and can be found in the literature [2–14].

The vertical channel is a frequently encountered configuration in thermal engineering equipments, for example, collector of solar energy, cooling devices of electronic and micro-electronic equipments, etc. The influences of electrically conducting nanofluids, such as water mixed with a little acid and other ingredients in the presence of a magnetic field on the channel flow and heat transfer have been reported in literature. Due to its wide applications, numerous investigations have been done toward the understandings of fully developed mixed convection flow in a vertical channel filled with nanofluids. The case of fully developed mixed convection between horizontal parallel plates with a linear axial temperature distribution was solved by Gill and Del Casal [15].

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Ostrach [16] solved the problem of fully developed mixed convection between vertical parallel plates with and without heat sources. Cebeci et al. [17] performed numerical calculations of developing laminar mixed convection between vertical parallel plates for both cases of buoyancy aiding and opposing conditions. Wirtz and McKinley [18] conducted an experimental study of an opposing mixed convection between vertical parallel plates with one plate heated and the other adiabatic. Lavine [19] presented the fully developed opposing mixed convection between inclined parallel plates. The natural convection cooling of vertical rectangular channel in air considering thermal radiation and wall conduction has been studied by Hall et al. [20]. Al-Nimr and Haddad [21] have described the fully developed free convection in an open-ended vertical channel partially filled with porous material. Greif et al. [22] have made an analysis on the laminar convection of a radiating gas in a vertical channel. The effect of wall conductances on the convective magnetohydrodynamic channel flow has been investigated by Yu and Yang [23]. Gupta and Gupta [24] have studied the radiation effect on a hydromagnetic convective flow in a vertical channel. Datta and Jana [25] have studied the effect of wall conductances on a hydromagnetic convection of a radiation gas in a vertical channel. The combined forced and free convective flow in a vertical channel with viscous dissipation and isothermal-isoflux boundary conditions have been studied by Barletta [26]. Barletta et al. [27] have presented a dual mixed convective flow in a vertical channel. Barletta et al. [28] have described a buoyant MHD flow in a vertical channel. Maïga et al. [29] have analysed the heat transfer behaviours of nanofluids in a uniformly heated tube. Maïga et al. [30] have studied the heat transfer enhancement by using nanofluids in forced convection flows. Polidori et al. [31] have presented the heat transfer modelling of Newtonian nanofluids in laminar free convection. Hang and Pop [32] have examined the fully developed mixed convection flow in a vertical channel filled with nanofluids. Maghrebi et al. [33] have studied the forced convective heat transfer of nanofluids in a porous channel. Grosan and Pop [34] have presented the fully developed mixed convection in a vertical channel filled with nanofluid. Sacheti et al. [35] have studied the transient free convective flow of a nanofluid in a vertical channel. The mixed convection flow of a nanofluid in a vertical channel has been presented by Xu et al. [36]. Fakour et al. [37] have described the mixed convection flow of a nanofluid in a vertical channel. Nield and Kuznetsov [38] have discussed the forced convection in a channel occupied by a nanofluid. The magnetohydrodynamic flow in a permeable channel filled with nanofluid has been investigated by Sheikholeslami and Ganji [39].

The objective of the present attempt is to study the hydromagnetic fully developed mixed convective flow in a vertical channel filled with nanofluids in the presence of a uniform transverse magnetic field. Both walls of the channel are kept at a temperature which varies linearly with the distance along the channel walls. In this present study, we extend the work of Hang and Pop [32] to consider the effect of magnetic field on the fully developed mixed convective flow in a vertical channel filled with nanofluids. The magnetic Reynolds number is large enough such that the induced magnetic field can not be neglected. The governing equations are solved analytically. The effects of the pertinent parameters on the fluid temperature, velocity and induced magnetic fields are investigated and analysed with the help of their graphical representations. Mixed convection in ducts and channels has received a great deal of attention in the literature. The majority of the work has addressed the regular fluid flows. The present attempt is to extend the mixed convection heat transfer in nanofluids. This study finds applications in materials processing which combines buoyancy force and magnetic field simultaneously to modify nanofluid properties.

2. Formulation of the problem and its solutions

Consider the flow of an electrically conducting fluid inside a vertical channel formed by two parallel plates. The distance between the channel walls is $2L$. The channel walls are assumed electrically non-conducting. Employ a Cartesian co-ordinates system with x-axis vertically upwards along the direction of flow and y-axis perpendicular to it. The origin of the axes is such that the channel walls are at positions $y=-L$ and $y=L$ as shown in Fig. 1. A uniform magnetic field B_0 acts normal to the plates. The fluid is a water based nanofluid containing three types of nanoparticles Cu, Al_2O_3 and TiO_2. It is assumed that the base fluid and the suspended nanoparticles are in a thermal equilibrium. The thermophysical properties of nanofluids are given in Table 1. The density is assumed to be linearly dependent on temperature buoyancy forces in the equations of motion.

Under the usual Boussinesq approximation, the MHD mixed convective nanofluid flow governed by the following equations ([32])

$$-\frac{\partial p}{\partial x}+\mu_{nf}\frac{d^2u}{dy^2}+\frac{B_0}{\mu_e}\frac{dB_x}{dy}+(\rho\beta)_{nf}g(T-T_w)=0, \tag{1}$$

$$\frac{\partial p}{\partial y}+\frac{B_x}{\mu_e}\frac{dB_x}{dy}=0, \tag{2}$$

where u is the fluid velocity along the x-direction, μ_e the magnetic permeability, μ_{nf} the dynamic viscosity of the nanofluid, ρ_{nf} the density of the nanofluid which are given by

$$\mu_{nf}=\frac{\mu_f}{(1-\phi)^{2.5}},\quad \rho_{nf}=(1-\phi)\rho_f+\phi\rho_s, \tag{3}$$

where ϕ is the solid volume fraction of the nanoparticle ($\phi=0$ correspond to a regular fluid), ρ_f the density of the base fluid, ρ_s the density of the nanoparticle and μ_f the viscosity of the base fluid.

The energy and magnetic induction equations are

$$(\rho c_p)_{nf}u\frac{dT}{dx}=k_{nf}\frac{d^2T}{dy^2}, \tag{4}$$

$$0=\frac{d^2B_x}{dy^2}+\sigma_{nf}\mu_eB_0\frac{du}{dy}, \tag{5}$$

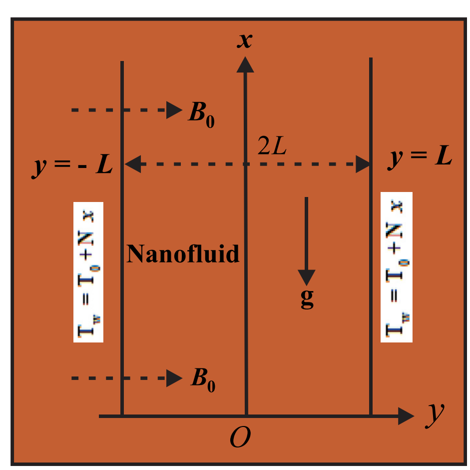

Fig. 1. Geometry of the problem.