Alexandria Engineering Journal (2016) 55, 253–262

HOSTED BY ELSEVIER

Alexandria University

Alexandria Engineering Journal

www.elsevier.com/locate/aej
www.sciencedirect.com

ORIGINAL ARTICLE

Transient natural convection in a vertical channel filled with nanofluids in the presence of thermal radiation

S. Das [a,*], R.N. Jana [b], O.D. Makinde [c]

[a] *Department of Mathematics, University of Gour Banga, Malda 732 103, India*
[b] *Department of Applied Mathematics, Vidyasagar University, Midnapore 721 102, India*
[c] *Faculty of Military Science, Stellenbosch University, Private Bag X2, Saldanha 7395, South Africa*

Received 8 June 2015; revised 12 October 2015; accepted 28 October 2015
Available online 11 November 2015

KEYWORDS

Natural convection;
Nanofluids;
Thermal radiation;
Vertical channel;
PST and PHF

Abstract The transient natural convection in a vertical channel filled with nanofluids has been studied when thermal radiation is taken into consideration. The equations governing the flow are solved by employing the Laplace transform technique. Exact solutions for the velocity and temperature of nanofluid are obtained in cases of both prescribed surface temperature (PST) and prescribed heat flux (PHF). The numerical results for the velocity and temperature of nanofluid are presented graphically for the pertinent parameters and discussed in detail. The fluid velocity is greater in the case of PST than that of PHF.

1. Introduction

Nanoparticle research is currently an area of intense scientific interest due to a wide variety of potential applications in biomedical, optical and electronic field. Nanotechnology has received extensive attention in recent years due to enormous applications in engineering, food and industrial, transportation, electronics, biomedicine, nuclear rectors, automobiles, drug delivery and biological sensors. Nanofluids are engineered by suspending nanoparticles with average sizes 1–100 nm. *Nano-fluids* is a term first introduced by Choi [1] and refers to a new class of heat transfer fluids with superior thermal properties. The mixture of the base fluid and nanoparticles having unique physical and chemical properties is referred to as a nanofluid. It is expected that the presence of the nanoparticles in the nanofluid enhances the thermal conductivity and therefore substantially enhances the heat transfer characteristics of the nanofluid. Nanofluids can be defined as the dilution of nanometer-sized particles (smaller than 100 nm) in a fluid [2], and nanofluids can be produced by dispersed evenly nanoparticles in a base fluid, such as water, ethylene glycol and oil [3]. The nanofluids usually contain the nanoparticles such as metals, oxides, carbides or carbon nanotubes, whereby these nanoparticles have unique chemical and physical properties [4]. Recently, there is a great progress in a new generation of magneto-nanofluids which provide very desirable features in materials processing, energy applications and also medical engineering. Many engineering processes

* Corresponding author. Tel.: +91 3222 261171.
E-mail addresses: tutusanasd@yahoo.co.in (S. Das), jana261171@yahoo.co.in (R.N. Jana).
Peer review under responsibility of Faculty of Engineering, Alexandria University.

http://dx.doi.org/10.1016/j.aej.2015.10.013
1110-0168 © 2015 Faculty of Engineering, Alexandria University. Production and hosting by Elsevier B.V.

occur at high temperatures, and the knowledge of radiative heat transfer plays significant role in the design of equipment. Nuclear power plants, gas turbines and various propulsion devices for aircraft, missiles, satellites and space vehicles are examples of such engineering processes.

Convective flows in vertical channels are significant in the improvement of cooling systems in heat exchangers, solar cells, nuclear reactors, and many other electrical and industrial appliances. Mainly affected by the buoyancy forces, such flows are largely studied as means to facilitate the thermal performance in several industrial processes. Low thermal conductivity of common fluids such as water and oil has proven to be a big hurdle in the use of such fluids as facilitators of heat transfer. This fact has persuaded engineers to design fluids with enhanced thermal conductivity and prevent the energy loss. There are many studies of nanofluids in different geometries. In contrary, the number of studies on natural and mixed convection of nanofluids in vertical or horizontal channels is limited. Grosan and Pop [5] have presented the fully developed mixed convection in a vertical channel filled by a nanofluid. Sacheti et al. [6] have studied the transient free convective flow of a nanofluid in a vertical channel. Maghrebi et al. [7] have presented the forced convection heat transfer of nanofluids in a porous channel. Motsumi and Makinde [8] have examined the effects of thermal radiation and viscous dissipation on boundary layer flow of nanofluids over a permeable moving flat plate. The natural convective heat transfer in square cavity by utilizing nanofluids in the presence of magnetic field and uniform heat generation/absorption has been presented by Teamah and El-Maghlany [9]. Rossi di Schio [10] have examined the effect of Brownian diffusion and thermophoresis on the laminar forced convection of a nanofluid in a channel. Xu et al. [11] have analyzed the mixed convection flow of a nanofluid in a vertical channel. Nandeppanavar et al. [12] have studied the MHD flow and heat transfer over a stretching surface with variable thermal conductivity and partial slip. Fakour et al. [13] have described the mixed convection flow of a nanofluid in a vertical channel. Nield and Kuznetsov [14] have investigated the forced convection in a parallel-plate channel occupied by a nanofluid. The nanofluid flow over an unsteady stretching surface in the presence of thermal radiation has been studied by Das et al. [15]. Das and Jana [16] have presented the natural convective magnetonanofluid flow and radiative heat transfer past a moving vertical plate. Pourmehran et al. [17] have made an analytical investigation of squeezing unsteady nanofluid flow between parallel plates.

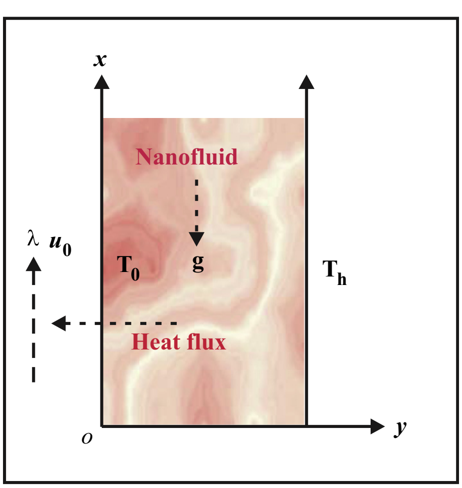

Figure 1 Geometry of the problem.

The aim of our present paper was to examine the effects of thermal radiation on an unsteady natural convective flow of a viscous incompressible nanofluid in a vertical channel. Assume that the flow is laminar and the fluid is gray absorbing–emitting radiation but no scattering medium. Closed form solutions of the initial and boundary value problems that govern the flow are obtained for two different types of boundary heating, namely, the prescribed surface temperature (PST) case and the prescribed heat flux (PHF) case. The results for the fluid velocity and temperature profiles are presented graphically and discussed for the pertinent flow parameters.

2. Formulation of the problem and its solution

Consider the unsteady flow of an electrically conducting nanofluid bounded by two infinitely long vertical parallel plates separated by a distance h. Choose a Cartesian co-ordinates system such that the x-axis along the direction of the flow vertically upward and y-axis perpendicular to the channel plates as shown in Fig. 1. Initially, at time $t = 0$, the channel plates and the fluid are assumed to be at the same temperature T_h and stationary. At time $t > 0$, the channel plate at $y = 0$ moves with the velocity λu_0 and the temperature of the plate at $y = 0$ is raised or lowered to T_0 (for PST case) and the rate of heat transfer at the plate ($y = 0$) is constant (for UHF case). It is assumed that the flow is entirely driven by the motion of the channel plate $y = 0$ as well as thermal buoyancy force. It is also assumed that the radiative heat flux in the x-direction is negligible as compared to that in the y-direction. The fluid density is assumed to be linearly dependent on the temperature buoyancy force in the equations of motion. As the channel plates are infinitely long, the velocity and temperature fields are functions of y and t only. The fluid is a water based nanofluid containing three nanoparticles, copper (Cu), aluminum oxide (Al_2O_3) and titanium dioxide (TiO_2). The nanoparticles are assumed to have a uniform shape and size. Moreover, it is assumed that both the base fluid and nanoparticles are in thermal equilibrium state. The thermophysical properties of the nanofluid are given in Table 1.

The unsteady natural convective flow of a radiating fluid, under usual Boussinesq approximation, is governed by the following equations

$$\rho_{nf}\frac{\partial u}{\partial t} = \mu_{nf}\frac{\partial^2 u}{\partial y^2} + g(\rho\beta)_{nf}(T - T_h), \tag{1}$$

$$(\rho c_p)_{nf}\frac{\partial T}{\partial t} = k_{nf}\frac{\partial^2 T}{\partial y^2} - \frac{\partial q_r}{\partial y}, \tag{2}$$

where u is the velocity along the x-directions, T the temperature of the nanofluid, μ_{nf} the dynamic viscosity of the nanofluid, β_{nf} the thermal expansion coefficient of the nanofluid, ρ_{nf} the density of the nanofluid, k_{nf} the thermal conductivity of the nanofluid, q_r the radiative heat flux and $(\rho c_p)_{nf}$ the heat capacitance of the nanofluid which are given by