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A numerical investigation of transient natural convection heat transfer of aqueous nanofluids in a differentially heated square cavity ☆

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ABSTRACT

Transient natural convection heat transfer of aqueous nanofluids in a differentially heated square cavity is investigated numerically. The effective thermal conductivity and dynamic viscosity of nanofluids are predicted by using the proposed models that take the contribution of Brownian motion of nanoparticles into account. Three different Rayleigh numbers and five different volume fractions of nanoparticles are considered. The development of natural convection is presented through the evolutions of the average Nusselt number along the cold side wall. The predicted flow development times and time-averaged Nusselt numbers are scaled with Rayleigh number. In addition, the time-averaged Nusselt numbers are presented in terms of volume fraction of nanoparticles. It is shown that at constant Rayleigh numbers, the time-averaged Nusselt number is lowered with increasing volume fraction of nanoparticles.

1. Introduction

Natural convection heat transfer in a differentially heated rectangular/square cavity has long been studied as it is a representative model problem for numerous engineering applications. In contrast to the great efforts devoted to investigating steady state heat transfer characteristics, few studies on transient natural convection heat transfer in such geometry have been conducted [1–3]. Since the middle of the 1990s, the research on nanofluids (nanoparticle colloidal suspensions) as emerging superior heat transfer fluids has received increasing attention [4]. Natural convection of nanofluids in a rectangular cavity has been investigated numerically for a variety of aspect ratios and thermal boundary conditions [5–11]. In addition, the effects of inclination angle of the cavity on natural convection heat transfer of nanofluids have been studied [12–14]. Without loss of generality, water has been mostly chosen as the base liquid for nanofluids, whereas various materials of nanoparticles have been considered. Nanofluids were usually treated as single-phase fluids with effective thermophysical properties being predicted by using existing models. Based on different theories and experimental data, a great number of models have been proposed, especially for predicting thermal transport properties, i.e., thermal conductivity and dynamic viscosity, of nanofluids. Recently, the influence of use of different models on prediction of natural convection heat transfer of nanofluids in rectangular cavities has been examined [15–18].

The aforementioned literature survey reveals that although many numerical efforts have been made to investigate steady state natural convection heat transfer of nanofluids in a rectangular cavity, there is a lack of exploration on the transient features. Therefore, this paper deals with a numerical study of transient natural convection heat transfer of aqueous nanofluids in a differentially heated square cavity.

2. Problem statement

2.1. Physical model and mathematical formulation

The physical model considered is shown schematically in Fig. 1. The side L of the square cavity is chosen as the characteristic length. The Cartesian coordinate system is adopted in such a way that the origin is placed at the left bottom corner and the x- and y-axes are measured towards right and upwards, respectively. Hence, gravity acts along the negative y-axis (downwards). Initially, the cavity and the enclosed quiescent nanofluids are maintained isothermally at a temperature T_0. The temperature on the left side wall is then suddenly increased to and thereafter kept at a temperature T_H ($>T_0$), with the temperature on the right side wall remaining at the initial value ($T_C=T_0$) and the top and bottom walls being insulated.

The mathematical formulation is simplified by considering the aqueous nanofluids as Newtonian and incompressible fluids, and by neglecting the viscous heating and radiation. Furthermore, employing the Boussinesq approximation for buoyancy, the governing equations

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