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Fully HOC Scheme for Mixed Convection Flow in a Lid-Driven Cavity Filled with a Nanofluid

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Abstract. A fully higher-order compact (HOC) finite difference scheme on the 9-point two-dimensional (2D) stencil is formulated for solving the steady-state laminar mixed convection flow in a lid-driven inclined square enclosure filled with water-Al_2O_3 nanofluid. Two cases are considered depending on the direction of temperature gradient imposed (Case I, top and bottom; Case II, left and right). The developed equations are given in terms of the stream function-vorticity formulation and are non-dimensionalized and then solved numerically by a fourth-order accurate compact finite difference method. Unlike other compact solution procedure in literature for this physical configuration, the present method is fully compact and fully higher-order accurate. The fluid flow, heat transfer and heat transport characteristics were illustrated by streamlines, isotherms and averaged Nusselt number. Comparisons with previously published work are performed and found to be in excellent agreement. A parametric study is conducted and a set of graphical results is presented and discussed to elucidate that significant heat transfer enhancement can be obtained due to the presence of nanoparticles and that this is accentuated by inclination of the enclosure at moderate and large Richardson numbers.

AMS subject classifications: 35K57, 65N06, 76T20

Key words: HOC difference scheme, pseudo-time derivative, mixed convection, ADI method.

1 Introduction

Suspensions of colloidal particles dubbed as nanofluids was pioneered by Choi [1], in which small amounts of metallic or metallic oxide nanoparticles are dispersed into wa-

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ter and other fluids. The nanofluid does not simply refer to a liquid-solid mixture, and some special requirements are necessary, such as even suspension, stable suspension, durable suspension, low agglomeration of particles, and no chemical change of the fluid. Various types of powders such as metallic, non-metallic and polymeric particles can be added into fluids to form slurries. In conventional cases, the suspended particles are of μm or even nm dimensions [2]. It has been shown experimentally [3, 4] that nanofluids can have anomalously higher thermal conductivities than that of the base fluid, thus posing as a promising alternative for thermal applications. The convective heat transfer characteristic of nanofluids depends on the thermo-physical properties of the base fluid and the ultra fine particles, the flow pattern and flow structure, the volume fraction of the suspended particles, the dimensions and the shape of these particles [5]. The utility of a particular nanofluid for a heat transfer application can be established by suitably modeling the convective transport in the nanofluid [6]. As revealed in the recent comprehensive reviews [7, 8], over the past decade there have been tremendous attempts to identify and model mechanisms of thermal conductivity enhancement of nanofluids, including size and shape of the nanoparticles, the hydrodynamic interaction between nanoparticles and base fluid, clustering of particles, temperature or Brownian motion, and so on. Khanafer et al. [9] investigated the problem of buoyancy-driven heat transfer enhancement of nanofluids in a 2D enclosure. Jou and Tzeng [10] reported a numerical study of the heat transfer performance of nanofluids inside 2D rectangular enclosures. Their results indicated that increasing the volume fraction of nanoparticles produced a significant enhancement of the average rate of heat transfer.

Mixed convection flow and heat transfer in enclosures is of interest in engineering and science. Its applications include nuclear reactors, lakes and reservoirs, solar collectors and crystal growth. Moreover, the flow and heat transfer in a shear driven cavity arises in industrial processes such as food processing and float glass production [11, 12]. Combination of buoyancy forces due to the temperature gradient and forced convection due to shear forces results in a mixed convection heat transfer situation, which is a complex phenomenon due to the interaction of these forces. Numerous studies on single or double lid-driven cavity flow and heat transfer involving different cavity configurations, various pure fluids and imposed temperature gradients have been continually published in the literature. Both thermally stable and unstable lid-driven flows inside enclosures have been investigated numerically by Torrance et al. [13] for fixed values of Reynolds and Prandtl numbers. Their numerical results have indicated that the Richardson number is a controlling parameter for the problem. Later on, Iwatsu et al. [14] have studied numerically mixed convection heat transfer in a driven cavity with a stable vertical temperature gradient. Their results have shown that the flow features are similar to those of a conventional driven-cavity of a non-stratified fluid for small values of the Richardson number. All of the above mixed convection studies were done for a pure base fluid without nanoparticles. A literature survey indicates that few studies have been done on mixed convection in a lid-driven cavity for a nanofluid compared to the natural convection case [5]. For example, Tiwari and Das [15] investigated numerically heat transfer