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Simulation of natural convection and entropy generation of non-Newtonian nanofluid in an inclined cavity using Buongiorno's mathematical model (Part II, entropy generation)

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ABSTRACT

In this paper, entropy generation of associated with the natural convection of non-Newtonian nanofluid, using the Buongiorno's mathematical model in an inclined cavity has been analyzed by Finite Difference Lattice Boltzmann method (FDLBM). The cavity is filled with nanofluid which the mixture shows shear-thinning behavior. This study has been performed for the certain pertinent parameters of Rayleigh number ($Ra = 10^4$ and 10^5), inclined angle ($\theta = 0^\circ, 40^\circ, 80^\circ, 120^\circ$), buoyancy ratio number (Nr = 0.1, 1, and 4), power-law index (n = 0.4 − 1), Lewis number (Le = 1, 5, and 10), Thermophoresis parameter (Nt = 0.1, 0.5, 1), and Brownian motion parameter (Nb = 0.1, 1, 5). The Prandtl number is fixed at Pr = 1. The Results indicate that the augmentation of the power-law index enhances various entropy generations in different Rayleigh numbers and inclined angles. The lowest total entropy generation was observed in the inclined angle of $\theta = 0^\circ$ in different Rayleigh numbers. In addition, the highest values of Bejan number was found in the inclined angle of $\theta = 0^\circ$ in various Rayleigh numbers. The enhancement of the Lewis number provokes the total irreversibility to rise. Further, the total entropy generation increases as the buoyancy ratio number augments. It was shown that the increase in the Brownian motion and Thermophoresis parameters enhance the total irreversibility.

1. Introduction

1.1. Background

Cooling technology is one of the most significant challenges in many different industries, e.g. electronic devices, chemical vapor deposition instruments (CVD), furnace engineering, solar energy collectors, phase change material, building energy systems, and non-Newtonian chemical processes. An innovative technique to improve heat transfer is using nanoparticles in the base fluids that have low thermal conductivity. Fluids with nanoparticles suspended in them are called nanofluids. Nanofluids have anomalous high thermal conductivity at very low nanoparticles concentration and considerable enhancement of forced convective heat transfer. Flow in an enclosure driven by buoyancy force is a fundamental problem in fluid mechanics and heat transfer as a validation in academic researches and various engineering applications. Many studies into natural convection of nanofluid in an enclosure have been conducted numerically and experimentally by different researchers [1–10]. In the most investigations, nanofluid is simulated, employing the single phase model without studying the Thermophoresis and Brownian motion parameters. However; recently, the two-phase model is applied to study the topic by some researchers where the nanoparticle concentration is not uniform. In fact, Brownian motion and Thermophoresis parameters have been considered [11–13]. The optimal design of heat transfer process in different industries is obtained with precision calculation of entropy generation since it clarifies energy losses in a system evidently. Hence, entropy generation is investigated into natural convection of pure fluids [14,15] and single phase nanofluids in multifarious shapes extensively [16–22]. For the all of the mentioned numerical investigations, the base fluid was assumed to be Newtonian, but it has been demonstrated by many researchers that the vast majority of nanofluids exhibit non-Newtonian, mainly

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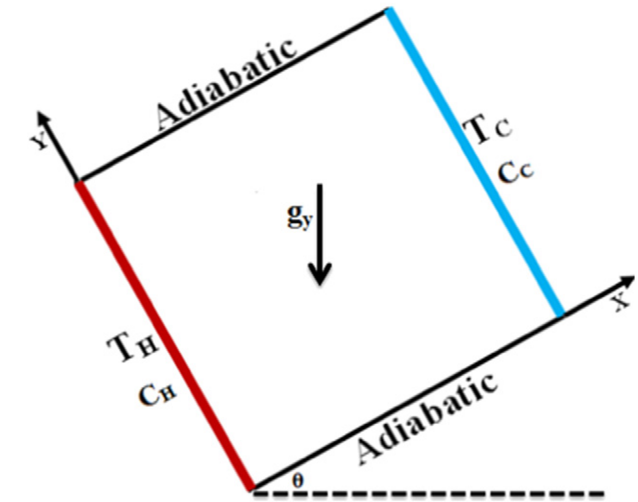

Fig. 1. Geometry of the present study.

shear-thinning, behavior [23–29]. Therefore, it is necessary that the effect of shear-thinning behavior of nanofluids to be considered. In the following sections of the introduction part, the previous studies have been explained and also the main aims of this investigation have been stated.

1.2. Literature review

Ilis et al. [14] investigated entropy generation in rectangular cavities with different aspect ratios numerically. It was demonstrated that heat transfer and fluid friction irreversibility in a cavity vary considerably with the studied aspect ratios. In addition, the total entropy generation in a cavity increases with Rayleigh number, however, the rate of increase depends on the aspect ratio. El-Maghlany et al. [15] analyzed entropy generation associated with laminar natural convection in an infinite square cavity, subjected to an isotropic heat field with various intensities for different Rayleigh numbers. Entropy generation is investigated into natural convection of nanofluids widely. Shahi et al. [16] studied the entropy generation induced by natural convection heat transfer in a square cavity containing Cu-water nanofluid and a protruding heat source. It was found that the Nusselt number increases and the entropy generations reduce as the nanoparticle volume fraction rises. In addition, it was shown that the heat transfer performance could be maximized and the entropy generation minimized by positioning the heat source on the lower section of the cavity wall. Esmaeilpour and Abdollahzadeh [17] examined the natural convection heat transfer behavior and entropy generation rate in a Cu-water nanofluid-filled cavity comprising two vertical wavy surfaces with different temperatures and two horizontal flat surfaces with thermal insulation. The results indicated that the mean Nusselt number and entropy generation rate both decrease as the volume fraction of nanoparticles increases. It was also exhibited that the mean Nusselt number and rate of entropy generation both augment with the enhancement of Grashof number, but decline as surface amplitude grows. Cho et al. [18] investigated the natural convection heat transfer performance and entropy generation rate in a

Table 1
Comparison between present study and Ilis et al. [14] at Ra = 10^5 and Pr = 0.70.

	Be_{avg}	St_{max}	Sf_{max}	Ss_{max}
Present study	0.314	61.09	563.28	597.19
Ilis et al. [14]	0.318	61.03	563.20	597.11

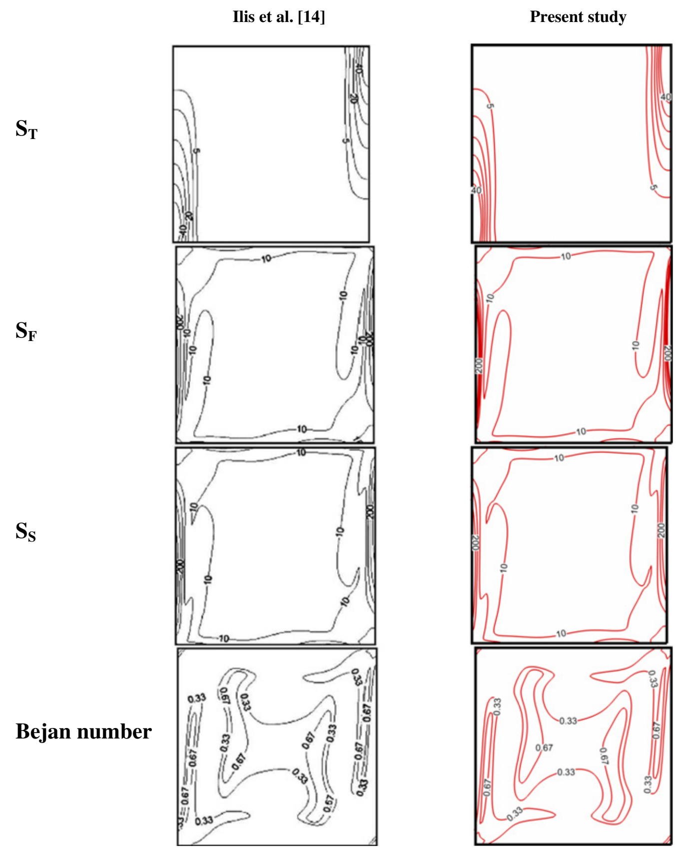

Fig. 2. Comparison between present study and Ilis et al. [14].

water based nanofluid-filled cavity bounded by a left wavy wall with a constant heat flux, a right wavy-wall with a constant low temperature, and flat upper and lower walls with adiabatic conditions. The results showed that the mean Nusselt number increases and the entropy generation rate decreases as the volume fraction of nanoparticles enhances. Further, it was shown that the mean Nusselt number could be maximized and the entropy generation minimized by carefully controlling the geometry parameters of the two wavy surfaces. Cho [19] performed a numerical simulation into the heat transfer performance and entropy generation of natural convection in a partially-heated wavy wall square cavity filled with Al_2O_3-water nanofluid. In the study, it was mentioned that the mean Nusselt number increases and the total entropy generation decreases as the volume fraction of Al_2O_3 nanoparticles rises. Sheikholeslami et al. [20] applied LBM to study nanofluid flow, heat transfer, and entropy generations in a square enclosure containing a rectangular heated body computationally. They indicated that the dimensionless entropy generation number increases with the rise of Rayleigh number and volume fraction of the nanoparticles. Kefayati [21] scrutinized entropy generation due to natural convection in an enclosure filled with non-Newtonian nanofluid. The single phase method was employed to simulate the problem. It was indicated those entropy generations due to fluid friction and heat transfer rise as the Rayleigh number enhances. In addition, augmentation of volume fraction enhances entropy generations due to heat transfer and fluid friction in different power-law indexes. Moreover, the total entropy generation declines slightly as power-law index increases. Kefayati [22] analyzed heat transfer and entropy generation on laminar natural convection of non-Newtonian nanofluids in a porous square cavity by Finite Difference Lattice Boltzmann Method (FDLBM). The porous cavity was filled with water and nanoparticles