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Numerical modeling of nanofluid flow inside a square cavity

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Abstract

In this study, the hydrodynamic and thermal behavior of nanofluid flow of iron oxide water in a square Cavity with different sides under a magnetic field for different values of Hartmann number and Riley number has been investigated. The effect of magnetic field, the effect of changing the angle of the chamber wall specific angles (θ), volume ratio changes of nanoparticles in Reynolds numbers 10 and 100 and in Richardson numbers 0.1 and 1 in the slow flow range are investigated in two dimensions. Increasing the Reynolds number increases the flow velocity, and increasing the flow velocity not only directly affects flow regime and pattern, but the displacement heat transfer coefficient, increase in the Nusselt number. The average Nusselt number increases with the increasing Richardson number. This increase is especially noticeable in higher Reynolds numbers. By increasing the tilt angle from 30 degrees to 90 degrees, the amount of heat transfer increases a very steep slope. For Reynolds number 100 and Richardson number 1, nanofluid with 3% volume fraction at 90 degree angle has the highest dimensionless Nusselt number. For Reynolds 10 and Richardson 1, the difference between the maximum and minimum velocities along the x-axis is maximal.

Keywords: oblique square Cavity, magnetic field, nanofluid flow, computational fluid dynamics, nanofluid two-phase modeling.

1. Introduction

Heat transfer has always been one of the most important and influential aspects of human life [1]. Many researches have been done in this field for many years, most of which have been done to improve and accelerate heat transfer. Therefore, this field of science remains one of the most important areas for the activity of researchers and scientists, as much research has been done and many studies have been conducted. Heat transfer had three mechanisms and it can be said that the most widely used heat transfer mechanism is displacement in which the presence of fluid plays an important role [2]. In heat exchangers with different cross-sectional surfaces for inlet and outlet channels, the surface of triangular cross-sections with equal sides creates the maximum cross-sectional area of heat transfer relative to the volume [1-8]. The reason for the increase in heat transfer due to the presence of nanofluids is the increase in the thermal conductivity of the working fluid compared to the initial state [9]. In addition to the factors that increase heat transfer, we can mention the use of magnetohydrodynamic currents (MHD). In recent years, due to its wide industrial applications, the study of magnetohydrodynamic current (MHD) in conductive fluids, such as liquid metals, has been widely considered by researchers. These currents in engineering and geophysics, control of unwanted displacement currents in the design of MHD generators, metal casting processes, crystal growth process optimization, plasma and nuclear reactor cooling industries, heat exchangers, heat exchangers, radiators, solar cooling systems, cooling systems High speed, they have. Using

MHD current, the flow and heat transfer inside the pipes can be controlled in the desired direction [15-10].

Many researchers have used ducts with non-circular cross-sections to increase the level of heat transfer in heat exchangers in industries such as automotive, power generation, heating and air conditioning, chemical engineering, chip cooling, aerospace, etc. [16]. The reason for the increase in heat transfer due to the presence of nanofluids is the increase in the thermal conductivity of the working fluid compared to the initial state [17-19]. In addition to the factors that increase heat transfer, we can mention the use of magnetohydrodynamic currents (MHD). Using MHD current, the flow and heat transfer inside the pipes can be controlled in the desired direction [23]. Shahsavar et al. [24] experimentally investigated the forced heat transfer of a slow flow of a fluid containing carbon nanotubes under the influence of a constant magnetic field. Sultanpour et al. [25] investigated the effect of magnetic field position on the rate of forced displacement heat transfer and the production of de nano-fluid entropy in the microchannel. In their research, they used water-aluminum oxide nanofluids with different volume percentages and also used a simple algorithm for their numerical simulation. Chamkha et al. [26] investigated the entropy generation and free heat transfer of copper-oxide nanofluids in a C-shaped cavity under a uniform magnetic field. Armaghani et al. [27] numerically studied the free transfer heat transfer and the production of water-aluminum oxide nanofluid entropy in the L-shaped baffle chamber. Saryazdi et al. [28] numerically investigated the forced heat transfer of nanofluids into a straight tube filled with a saturated porous material. In their research, they assumed the wall temperature to be constant. Ma et al. [29] numerically investigated the free transfer heat transfer of a nanofluid stream inside a U-shaped chamber equipped with a baffle under the influence of a magnetic field. They used the Latis-Boltzmann method in their research. Also, the effect of bromine movements on heat transfer has been considered. Gholinia et al. [30] investigated ethylene glycol-based nanofluids on a permeable circular cylinder under a magnetic field. They studied the combined heat transfer consisting of natural and forced displacement. Using the finite volume method, Ma et al. [31] simulated the natural heat transfer of a nanofluid inside a sloping Kuwaiti chamber in the presence of a constant temperature heat source.

2. Governing equations

The two-phase method has been used to model the nanofluid flow. In this method, the presence and dispersion of particles in the base fluid are considered separately. This method, as its name implies, follows the theory of Euler and Lagrange. The liquid phase acts as a continuous phase, the properties of which are determined by solving the Navier-Stokes equations, while the properties of the dispersed phase are determined by examining a large number of particles in the flow field and considering Newton's second law for each particle. The diffused phase can exchange momentum, mass, and energy with the liquid phase. For the liquid phase, the survival equations are expressed as follows:

3. Continuity

$$\nabla.(\rho_f \vec{v}_f) = 0 \qquad (1)$$

$$\nabla.(\rho_f \vec{v}_f \vec{v}_f) = -\nabla P + \nabla.(\mu_f \nabla \vec{v}_f) + \rho_f \vec{g} \beta (T - T_i) + \vec{S}_m \qquad (2)$$

In the above relation, S_m spring term expresses the momentum transferred between the fluid phase and the particle phase, which is determined by calculating the momentum change of the particles through the control volume.

$$\vec{S}_m = \sum \vec{F} m_p \Delta t \qquad (3)$$

Where m_p is the mass of the particle and $\vec{F}$ represents the sum of all the forces per unit mass of the nanoparticle that is applied to the particle, and the drag force, denoted by$\vec{F}_D$, the force of gravity, denoted by $\vec{F}_G$, the mass force Virtual, denoted by $\vec{F}_V$, Suffman's force, denoted by $\vec{F}_L$, thermophoretic force, denoted by $\vec{F}_T$, Brownian force, denoted by $\vec{F}_B$, and finally the pressure gradient force, denoted by Is denoted by $\vec{F}_P$, which is given below in the calculation relations of each.

It should be noted that for nanoparticles, the equation of particle motion can be expressed according to Newton's second law as follows:

$$F = \frac{d\vec{v}_p}{dt} \qquad (4)$$

For sub-micron particles, due to the low relative Reynolds number, the drag force is determined using Stokes' law as follows:

$$\vec{F}_D = \frac{18\mu}{d_p^2 \rho_p C_e} (\vec{v}_f - \vec{v}_p) \tag{5}$$

$$C_e = 1 + \frac{2\lambda}{d_p} (1.257 + 0.4 e^{-\left(\frac{1.1 d_p}{2\lambda}\right)}) \tag{6}$$

In the above relation, λ is the free path is a molecular medium.

The lifting force on a particle is created due to the rotation of the velocity gradient and can be calculated from the following relation:

$$\vec{F}_L = \frac{2Kv^{\frac{1}{2}} \rho d_{ij}}{\rho_p d_p (d_{lk} d_{kl})^{\frac{1}{4}}} \left(\vec{v}_f - \vec{v}_p\right) \tag{7}$$

Where $k = 2.594$ and d_{ij} is the deformation tensor. This form of lift force makes sense for fine particles.

It should be noted that this relationship can be used for particles smaller than microns.

Another force exerted on the fine particles dispersed in the fluid is the Brownian force. For sub-micron particles, the collision of particles with fluid molecules and thus the effect of Brownian motion is highlighted. The Brownian force components are modeled by the Gaussian perturbation process with the intensity of spectrum $S_{n.ij}$ according to which we have:

$$S_{ij}^n = S_0 \delta_{ij} \tag{8}$$

In the above relation, δ_{ij} is the Cronker Delta and

$$S_0 = \frac{216 v k_B T}{\pi^2 \rho_f d^S (\frac{\rho_p}{\rho_f})^2 C_e} \tag{9}$$

In the above relation, T is the absolute temperature of the fluid and v is the kinematic viscosity and K_B is the Boltzmann constant. The magnitude of the Brownian force components is as follows:

$$\vec{F}_{B.i} = \xi_i \sqrt{\frac{\pi S_0}{\Delta t}} \tag{10}$$

4. References

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