World Academy of Science, Engineering and Technology
International Journal of Mechanical and Mechatronics Engineering
Vol:10, No:12, 2016

Evaluation of Heat Transfer and Entropy Generation by Al_2O_3-Water Nanofluid

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Open Science Index, Mechanical and Mechatronics Engineering Vol:10, No:12, 2016 publications.waset.org/10006066.pdf

Abstract—In this numerical work, natural convection and entropy generation of Al_2O_3–water nanofluid in square cavity have been studied. A two-dimensional steady laminar natural convection in a differentially heated square cavity of length L, filled with a nanofluid is investigated numerically. The horizontal walls are considered adiabatic. Vertical walls corresponding to x=0 and x=L are respectively maintained at hot temperature, T_h and cold temperature, T_c. The resolution is performed by the CFD code "FLUENT" in combination with GAMBIT as mesh generator. These simulations are performed by maintaining the Rayleigh numbers varied as $10^3 \leq Ra \leq 10^6$, while the solid volume fraction varied from 1% to 5%, the particle size is fixed at dp=33 nm and a range of the temperature from 20 to 70 °C. We used models of thermophysical nanofluids properties based on experimental measurements for studying the effect of adding solid particle into water in natural convection heat transfer and entropy generation of nanofluid. Such as models of thermal conductivity and dynamic viscosity which are dependent on solid volume fraction, particle size and temperature. The average Nusselt number is calculated at the hot wall of the cavity in a different solid volume fraction. The most important results is that at low temperatures (less than 40 °C), the addition of nanosolids Al_2O_3 into water leads to a decrease in heat transfer and entropy generation instead of the expected increase, whereas at high temperature, heat transfer and entropy generation increase with the addition of nanosolids. This behavior is due to the contradictory effects of viscosity and thermal conductivity of the nanofluid. These effects are discussed in this work.

Keywords—Entropy generation, heat transfer, nanofluid, natural convection.

I. INTRODUCTION

NANO-FLUID is a new type of fluid firstly defined by Choi [1], when nanosolid particles (1-100 nm) with high thermal conductivity are suspended in a base liquid with low thermal conductivity. Nanofluids provide excellent thermophysical properties than traditional fluids.

Many researchers were interested by studying the heat transfer by natural convection in square cavities which can be used for several applications such as electronic cooling devices, heat exchangers, solar energy collectors and melting process. Recently, several studies have been reported for the natural convection heat transfer and entropy generation in nanofluids under different condition using different numerical approaches. For example, Ben-Cheikh et al. [2] studied natural convection in a square enclosure with non-uniform temperature distribution maintained at the bottom wall and filled with nanofluids. Their results indicated that increasing the volume fraction of nanoparticles produced a significant enhancement in heat transfer rate. Thus, they also observed that the heat transfer enhancement strongly depends on the type of nanofluids. Bouhalleb and Abbassi [3] reported a numerical investigation of the effect of solid volume fraction on heat transfer and fluid flow in the case of natural convection in inclined cavity filled with CuO-water nanofluid. The results show that the addition of CuO solid particle in water leads to enhancement of heat transfer. The average Nusselt number is influenced by the variation of aspect ratio and inclination angle. Hakan and Abu-Nada [4] performed a numerical study of natural convection in a partially heated enclosure filled with nanofluid. This study is done for nanofluids Al_2O_3, CuO and TiO_2. The results show that the mean Nusselt number increases with increasing the solid volume fraction of nanoparticles for whole range of Rayleigh numbers. They have noticed that heat transfer at low aspect ratios is more pronounced than at high aspect ratios. Ghasemi and Aminossadati [5] presented a numerical study of heat transfer by natural convection in inclined enclosure filled with CuO-water nanofluid. The results show that the heat transfer depends on the Rayleigh number, the angle of inclination and the solid volume fraction of the nanoparticles and they show that adding nanoparticles into pure water improves its heat transfer performance. Arifin et al. [6] have studied a two-dimensional laminar Marangoni boundary layer flow in a water based-nanofluid containing different types of nanoparticles: Cu, Al_2O_3 and TiO_2. It was found that nanoparticles with low thermal conductivity, TiO_2, have better enhancement of heat transfer compared to Al_2O_3 and Cu. For a particular nanoparticle, when the solid volume fraction increases, the interface velocity and the heat transfer rate decreases. Natural convection in enclosure filled with Al_2O_3-water nanofluid has been investigated by Nasrin et al. [7]. Their results show that the heat transfer is most effective when increasing the concentration of solid particle and Prandtl number as well as decreasing aspect ratios. The heat transfer enhancement utilizing water–Cu and water–Al_2O_3 nanofluids in a trapezoidal enclosure is achieved by Saleh et al. [8]. Various inclination angles of the sloping wall, solid volume fractions, and Grashof numbers were considered and the flow and temperature fields as well as the heat transfer was analyzed. They showed that the structure of the fluid flow within the enclosure depends upon, Grashof number,

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inclination angle of sloping wall and nanoparticles concentration and type. In addition, they found that sloping wall and Cu nanoparticles with high concentration can increase the rate of heat transfer. Santra et al. [9] studied heat transfer characteristics of a copper–water nanofluid in a differentially heated square cavity by treating the nanofluid as a non-Newtonian fluid and they reported a decrease in heat transfer by increasing the volume concentration of nanoparticles for a particular Rayleigh number. Natural convection in an open enclosure which is filled with a water/Cu nanofluid has been conducted numerically by Lattice Boltmann Method (LBM) by Kefayati [10]. They showed that the average Nusselt number increases with augmentation of Rayleigh number and the volume fraction of nanoparticles. They also showed that the average Nusselt number decreases as the aspect ratio increases at various Rayleigh numbers and different the nanoparticle volume fractions.

Sheikhzadeh et al. [11] studied the problem of the buoyancy-driven fluid flow and heat transfer in a square cavity with partially active side walls filled with Cu–water nanofluid. Their results showed that the average Nusselt number increases with increasing both the Rayleigh number and the volume fraction of the nanoparticles. Magherbi et al. [12] conducted a numerical study of the transient state of entropy generation for laminar natural convection in a square cavity with heated vertical walls. Results show that the total entropy generation has a maximum value at the onset of the transient state, which increases with the Rayleigh number and the irreversibility distribution ratio. Ilis et al. [13] studied the entropy generation due to natural convection in square cavity filled with the fluid for Prandtl number 0.7. Results show that with high value of Rayleigh number $Ra=10^5$, the total entropy generation due to fluid friction and total entropy generation number increase with increasing aspect ratio, attain a maximum and then decrease. Oliveski et al. [14] investigated numerically the entropy generation in rectangular cavities that were submitted to the natural convection process due to the temperature difference between the vertical walls. The numerical analysis is performed with five aspect ratios, five Rayleigh numbers and four irreversibility coefficients. The results of this work indicate that for the same aspect ratio, the entropy generation due to the viscous effects increases with the Rayleigh number. They also showed that, for a determined Rayleigh number, the entropy generation due to the viscous effects also increases according to the aspect ratio. In recent years, the problem of entropy generation in nanofluid filled cavities was the interest of many researches [15], [16]. The effect of different parameters on the entropy generation was studied such as solid volume fraction, particle size, Rayleigh number, effect of Prandtl number. Selimefendigil and Oztop [17] studied the natural convection and entropy generation of nanofluid filled cavity having different shaped obstacles with magnetic field effect. Their simulation results showed that averaged heat transfer reduces by 21.35%, 32.85% and 34.64% for the cavity with circular, diamond and squared shaped obstacles, respectively, compared to cavity without obstacles at $Ra = 10^6$. Cho [18] studied a numerical study of heat transfer characteristics and entropy generation of natural convection in a partially-heated wavy-wall square cavity filled with Al_2O_3–water nanofluid. The results show that the mean Nusselt number increases and the total entropy generation decreases as the volume fraction of Al_2O_3 nanoparticles increases. Moreover, he found that the mean Nusselt number reduces and the total entropy generation increases when the amplitude and wavelength of the wavy-surface increase. Moreover, the Bejan number increases with an increasing amplitude and increasing wavelength of the wavy-surface. Shahi et al. [19] investigated the natural convection heat transfer phenomenon in a square cavity containing Cu–water nanofluid and a protruding heat source. They observed that the Nusselt number increased and the entropy generation decreased as the volume fraction of nanoparticles increased. The results have shown that the maximum value of Nusselt number and minimum entropy generation are obtained when heat source mountains in the bottom horizontal wall.

Several researchers [20]-[22] studied the effect of temperature on the viscosity of nanofluids for different range of the particle size and the solid volume fraction. All these results show that the viscosity decreases considerably with the increase of temperature. Teng et al. [23] conducted experimental measurements to study the effect of particle size, temperature, and solid volume fraction on the thermal conductivity ratio of Al_2O_3-water nanofluid. They use different particle size (20, 50, and 100 nm) with different volume concentration (0.5, 1, 1.5, and 2 %). The temperatures used are 10, 30 and 50°C. They showed that the adding of Al_2O_3 nanosolids in water increases the thermal conductivity ratio of the nanofluid. They also showed that at a higher temperature, the thermal conductivity is increased. Finally, they proposed an empirical relation expressing the variation of thermal conductivity as a function of particle size, temperature and solid volume fraction. This empirical relation showed a good agreement with their experimental results. Li et al. [24] conducted experimental measurements of thermal conductivity and viscosity as functions of different parameters such as temperature and concentration of nanoparticles. The results show that when the temperature increases, the thermal conductivity increases whereas the dynamic viscosity decreases.

The addition of nanosolids into basic liquid lead to an augmentation not only of thermal conductivity but also of the dynamic viscosity. The first effect leads to the enhancement of heat transfer whereas the second leads to a decrease in heat transfer via the slowing of the flow motion. According to this bibliography, it seems that addition of nanosolids in basic fluid enhances heat transfer at room temperature [2]-[11]. These studies used theoretical models for viscosity such as Brinkman [25] and Batchelor [26]. Actually, many recent experimental measurements of nanofluid viscosity are available in literature. It turns out that theoretical models underestimate the viscosity especially at high concentrations of nanoparticles, and then the enhancement of heat transfer by nanofluid is not certain. In the present study, we used models for viscosity and thermal conductivity combining effects of temperature, concentration and nanoparticles size, based on experimental measurements of Al_2O_3-water nanofluid. We are used these models in order to confirm if nanofluid leads really to an increase in heat transfer. Afterwards, effects of adding solid particle into water in entropy generation of Al_2O_3-water nanofluid are presented in this works.

TABLE I
NOMENCLATURE

Symbol	Quantity
Cp	Specific heat at constant pressure ($J.kg^{-1}.K^{-1}$)
d_p	Nanoparticles diameter (m)
df	The equivalent diameter of fluid molecule (m)
g	Gravitational acceleration ($m.s^{-2}$)
k	Thermal conductivity ($Wm^{-1}K^{-1}$)
kr	Relative thermal conductivity (k_{nf}/k_f)
L	Length of the cavity (m)
Nu	Space averaged Nusselt number
P	Dimensionless pressure
Pr	Prandtl number(ν_f / α_f)
Ra	Rayleigh number ($g\beta_f L^3 \Delta T$ / $\nu_f \alpha_f$)
S''_{gen}	Dimensional entropy generation ($J.K^{-1}.m^{-3}.s^{-1}$)
S'''_{gen}	Dimensionless entropy generation
T	Temperature (K)
U,V	Dimensionless velocity components (normalized by α_f /L)
X, Y	Dimensionless coordinates (normalized by L)
Greek symbols	
α	Thermal diffusivity(k / ρC_p) ($m^2.s^{-1}$)
β	Thermal expansion coefficient (K^{-1})
δ	Irreversibility coefficient
$\emptyset$	Solid volume fraction
θ	Dimensionless temperature ($T - T_c$) / ($T_h - T_c$)
μ	Dynamic viscosity of the fluid (kg.m-1.s-1)
ν	Kinematic viscosity of the fluid (μ / ρ)($m^2.s^{-1}$)
ρ	Density (kg.m-3)
Subscripts	
c	cold
h	hot
f	fluid
nf	nanofluid
s	solid

II. PHYSICAL PROPERTIES OF NANOFLUIDS

Thermophysical properties of water and Al_2O_3 nanosolids at room temperature are presented in Table II.

TABLE II
PHYSICAL PROPERTY OF PURE WATER AND AL_2O_3 SOLID PARTICLES

	k ($wm^{-1}K^{-1}$)	ρ (kgm^{-3})	C_p ($J\ kg^{-1}K^{-1}$)	β (K^{-1})
water	0.613	997	4179	$2.1\ 10^{-4}$
Al_2O_3	40	3970	765	$8.5\ 10^{-6}$

The density of nanofluid is calculated from:

$$\rho_{nf} = (1-\emptyset)\rho_f + \emptyset\rho_s \tag{1}$$

Subscripts nf, f and s refer to the mixture nanofluid, the basic fluid and the solid particles respectively.

The expression of specific heat is given by [27] and thermal expansion coefficient is given by [5]. These relations are inspired from (1):

$$(\rho Cp)_{nf} = (1-\emptyset)(\rho Cp)_f + \emptyset(\rho Cp)_s \tag{2}$$

$$(\rho\beta)_{nf} = (1-\emptyset)(\rho\beta)_f + \emptyset(\rho\beta)_s \tag{3}$$

Brinkman [25] and Batchelor [26] proposed two equations of nanofluid viscosity as a function of volume fraction which are expressed respectively as:

$$\mu_{nf} = \frac{\mu_f}{(1-\emptyset)^{2.5}} \tag{4}$$

$$\mu_{nf} = (1 + 2.5\ \emptyset + 6.2\emptyset^2)\mu_f \tag{5}$$

The models of viscosity and thermal conductivity are expressed as functions of temperature based on experimental measurements of Al_2O_3-water nanofluid, are developed by [28]

$$k_r = 0.9843 + 0.398\ \emptyset^{0.7383}\left(\frac{1}{d_p}\right)^{0.2246}\left(\frac{\mu_{nf}}{\mu_f}\right)^{0.0235} - 3.9517\frac{\emptyset}{T} + 34.034\frac{\emptyset^2}{T^3} + 32.509\frac{\emptyset}{T^2} \tag{6}$$

$$\mu_f(T) = 2.414\ 10^{-5}10^{247.8/(T-140)} \tag{7}$$

$$\mu_{nf} = -0.4491 + \frac{28.837}{T} + 0.5740\emptyset - 0.1634\emptyset^2 + 23.053\frac{\emptyset^2}{T^2} + 0.0132\emptyset^3 - 2354.734\frac{\emptyset}{T^3} + 23.498\frac{\emptyset^2}{d_p^2} - 3.0185\frac{\emptyset^3}{d_p^2} \tag{8}$$

III. STATEMENT OF THE PROBLEM AND GOVERNING EQUATIONS

In the following, we study the effect of adding nanoparticles (Al_2O_3) into basic fluid (water) on heat transfer by natural convection in square cavity heated from one vertical side as indicated in Fig. 1. The nanofluid is considered as Newtonian and incompressible fluid. The flow is supposed to be laminar and bi-dimensional.

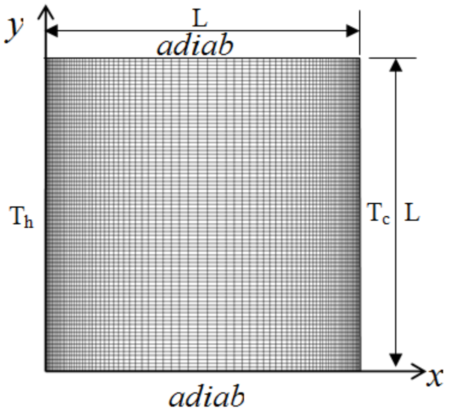


Fig. 1 Square cavity with grid meshing and boundary conditions

The numerical solutions of momentum and energy equations were performed to simulate the amount of heat transferred from the hot wall to the cold one. The resolution is obtained by the CFD code "FLUENT" in combination with "GAMBIT" as mesh generator.

The mathematical equations describing the nanofluid flow are the continuity, Navier-Stokes and energy equations:

$$\frac{\partial U}{\partial X}+\frac{\partial V}{\partial Y}=0 \tag{9}$$

$$U\frac{\partial U}{\partial X}+V\frac{\partial U}{\partial Y}=-\frac{\partial P}{\partial X}+\frac{\mu_{nf}}{\rho_{nf}\alpha_f}\left(\frac{\partial^2 U}{\partial X^2}+\frac{\partial^2 U}{\partial Y^2}\right) \tag{10}$$

$$U\frac{\partial V}{\partial X}+V\frac{\partial V}{\partial Y}=-\frac{\partial P}{\partial Y}+\frac{\mu_{nf}}{\rho_{nf}\alpha_f}\left(\frac{\partial^2 V}{\partial X^2}+\frac{\partial^2 V}{\partial Y^2}\right)+\frac{(\rho\beta)_{nf}}{\rho_{nf}\alpha_f}RaPr\theta \tag{11}$$

$$U\frac{\partial \theta}{\partial X}+V\frac{\partial \theta}{\partial Y}=\frac{\alpha_{nf}}{\alpha_f}\left(\frac{\partial^2 \theta}{\partial X^2}+\frac{\partial^2 \theta}{\partial Y^2}\right) \tag{12}$$

These equations are normalized by the characteristic side L of the square cavity and the specific velocity $\frac{\alpha_f}{L}$, where α_f is the thermal diffusivity of the basic fluid. The dimensionless temperature is defined as $\theta=(T-T_c)/(T_h-T_c)$.

The dimensionless numbers that appear in governing equations are the classic Prandtl and Rayleigh numbers designed by Pr and Ra respectively.

$$Pr=(\nu_f\ /\ \alpha_f)$$

$$Ra=(g\beta_f L^3\Delta T\ /\ \nu_f\alpha_f)$$

Heat transfer exchanged between the flow and the hot wall is evaluated by the space average Nusselt number expressed as:

$$Nu=-\frac{k_{nf}}{k_f}\int_0^1 \frac{\partial\theta}{\partial X}\Big)_{X=0}dy \tag{13}$$

In natural convection, the entropy generation is associated to the heat transfer and to the fluid flow friction. According to [29], the local entropy generation (s''_{gen}) can be determined by:

$$s''_{gen}=\frac{k_{nf}}{T_0^2}\left[\left(\frac{\partial T}{\partial x}\right)^2+\left(\frac{\partial T}{\partial y}\right)^2\right]+\frac{\mu_{nf}}{T_0}\left[2\left(\frac{\partial u}{\partial x}\right)^2+2\left(\frac{\partial v}{\partial y}\right)^2+\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)^2\right] \tag{14}$$

where $T_0=(T_h+T_c)/2$

The first term of (14) shows the local entropy generation due to heat transfer, while the second term shows the local entropy generation due to the viscous effects of the fluid. By using dimensionless parameters, the expression of the non-dimensional entropy generation, S'''_{gen} can be written by:

$$S'''_{gen}=\frac{k_{nf}}{k_f}\left[\left(\frac{\partial \theta}{\partial X}\right)^2+\left(\frac{\partial \theta}{\partial Y}\right)^2\right]+\frac{\mu_{nf}}{\mu_f}\delta\left[2\left(\frac{\partial U}{\partial X}\right)^2+2\left(\frac{\partial V}{\partial Y}\right)^2+\left(\frac{\partial U}{\partial Y}+\frac{\partial V}{\partial X}\right)^2\right] \tag{15}$$

$$S'''_{gen}=s''_{gen}\frac{T_0^2L^2}{k_f(T_h-T_c)^2} \tag{16}$$

$$\delta=\frac{\mu_f T_0}{k_f}\left(\frac{\alpha_f^2}{(T_h-T_c)^2L^2}\right) \tag{17}$$

where s''_{gen} and S'''_{gen} are dimensional and dimensionless entropy generations, respectively. δ is the irreversibility factor and the ratio of the viscous entropy generation to thermal entropy generation.

IV. GRID REFINEMENT AND TEST VALIDATION

To study the influence of the grid, we calculated the average Nusselt number at the hot wall for five non uniform grids. The results are related to pure water at Ra = 10^5 and the Prandtl number is set at 6.83. Table III presents the Nusselt number for different grids. When we pass from the grid 71x71 to the grid 81x81, Nu undergoes a variation of 1.3%. When we pass to the grid 91x91, the variation of Nu is only 0.04%. We conclude that the grid of 81x81 gives a good compromise between precision and calculation time and is sufficient to carry out a numerical study of this flow.

TABLE III
THE VARIATION OF THE NUSSELT NUMBER VERSUS GRID MESH

Grid	**51x51**	**61x61**	**71x71**	**81x81**	**91x91**
Nusselt	4.7572	4.7501	4.7452	4.7388	4.7366

The validation is performed for Rayleigh numbers ranging from 10^3 to 10^6. Table IV compares Nu of our simulations to the results of [30] and [31]. The maximum deviation of our numerical results to these references is less than 1.08%. We conclude that our simulations give acceptable results.

TABLE IV
VALIDATION TESTS

		Ra=10^3	**Ra=10^4**	**Ra=10^5**	**Ra=10^6**
Water	**Present study**	**1.1218**	**2.2856**	**4.7388**	**9.2717**
	Lai and Yang [30]	1.128	2.286	4.729	9.173
	Kahveci [31]	---	2.274	4.722	9.230

V. RESULTS AND DISCUSSIONS

At the molecular viewpoint when the temperature increases, the intermolecular distance becomes larger, which leads to the decrease of the viscosity and the agitation in microscopic scale becomes stronger leading to an increase in thermal conductivity. In this context, we have the idea to study the effects of temperature on viscosity, thermal conductivity and heat transfer in hope to find a situation where the addition of nanosolids lead to an increase in heat transfer. We propose to use the models of viscosity and thermal conductivity which are expressed as functions of temperature and developed by [28] based on experimental measurements of Al_2O_3-water nanofluid.

Fig. 2 presents a plot of relative thermal conductivity k_r a s a function of temperature. It is seen that, temperature has a significant effect on relative thermal conductivity, k_r increases considerably with increasing temperature. At ϕ=5%, k_r undergoes an increase of 17.41% when temperature pass from 20 to 70 °C. A total increase of 34% in k_r is recorded when we pass from T=20 °C and ϕ=0% to T=70 °C and ϕ=5%.

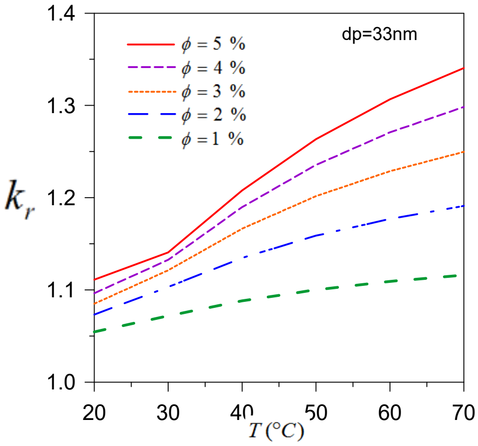


Fig. 2 Effect of temperature on the relative thermal conductivity of Al_2O_3-water

Concerning the viscosity from Fig. 3, we find that it decreases strongly with increasing temperature. At 5% solid volume fraction, viscosity of the nanofluid is found to be decreased by 56.25 % when the temperature pass from 20 to 70 °C.

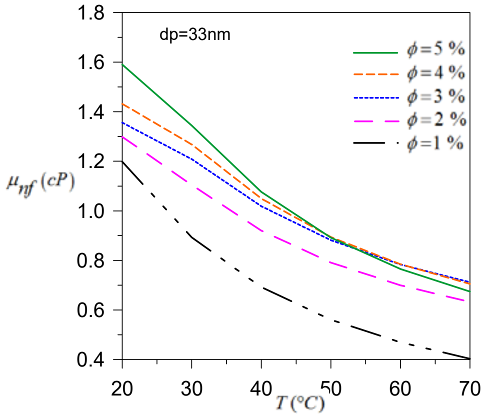


Fig. 3 Effect of temperature on Al_2O_3-water viscosity

The decrease in viscosity and increase in thermal conductivity due to an increase of the temperature seem to be very promising regarding the enhancement of heat transfer by the nanofluid Al_2O_3. In this regard, we computed the Nusselt number characterizing heat transfer as a function of temperature and results are presented in Fig. 4. It appears that Nusselt number increases considerably with increasing the mean temperature of the fluid for all concentrations. On the other hand, two interval temperature are remarkable; 20 °C≤ T≤40 °C and 40 °C≤ T≤70 °C. For the first interval, at a given temperature, the Nusselt number decreases when solid volume fraction increases meaning that the addition of nanosolids leads to a decrease in heat transfer, in this situation, the augmentation in viscosity prevails over the increase in conductivity even when temperature increases until 40 °C. For the second temperature interval, the Nusselt number increases when solid volume fraction increases, indicating that addition of nanosolids into water lead to an enhancement of heat transfer. Now the effect of increasing conductivity prevails over of the increase in viscosity when nanosolids Al_2O_3 are added into pure water.

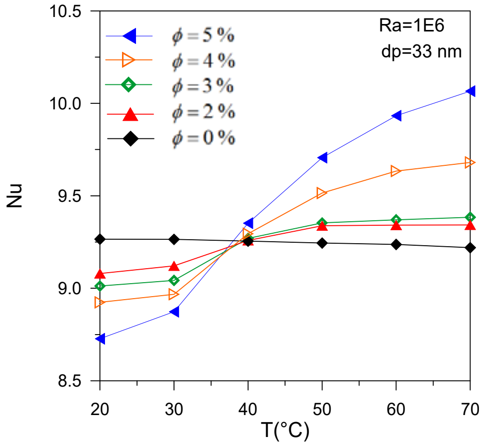


Fig. 4 Variation of Nusselt number with temperature for different solid volume fraction of Al_2O_3

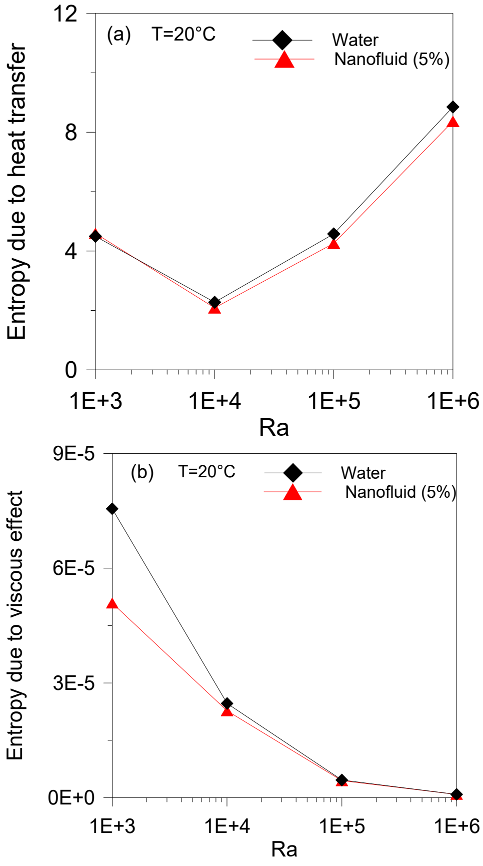


Fig. 5 (a) Entropy generation due to heat transfer effects, (b) Entropy generation due to viscous effects for different Ra at T=20°C

Variation of entropy generation due to heat transfer effects of the nanofluids at T=20 °C, is shown in Fig. 5 (a). From this figure, it is seen that at Rayleigh number equal to 10^3 and where the conduction that outweighs the entropy generation at 5% of nanofluid is higher than the entropy generation at pure water. At $Ra \geq 10^4$, the entropy generation due to heat transfer of nanofluid is lower than pure water. We also note that an increase in entropy generation as a function of *Ra* appears. Fig. 5 (b) shows the entropy generation due to viscous effects at T=20 °C. From this figure, we note that adding of particle solids into the pure water lead to decrease of the entropy generation due to viscous effects. In the present study, we remark that the entropy generation due to viscous effects is negligible with respect the entropy generation due to the heat transfer.

Fig. 6 summarizes the effect of the solid volume fraction and the temperature on the entropy generation at Ra=10^6. From this figure, it is seen that at T<40 °C, the total entropy is decreased when the concentration of the nanoparticle increased. For example, at T=20 °C, the total entropy generation is found to be decreased by 6% when the solid volume fraction passes from 0% to 5%. We can conclude that, at room temperature, adding nanoparticle solids into pure water leads to decrease in entropy generation. This is due to the fact that increasing effective viscosity leads to increase in fluid friction which has a trivial effect on entropy generation. On the other hand, atT $\geq$ 40°C, the total entropy generation undergoes an increase when the solid volume fraction increases. Such as at T=70 °C, the increase is of the order of 9%.

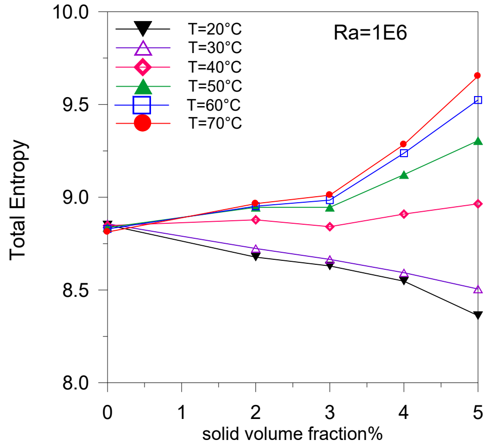
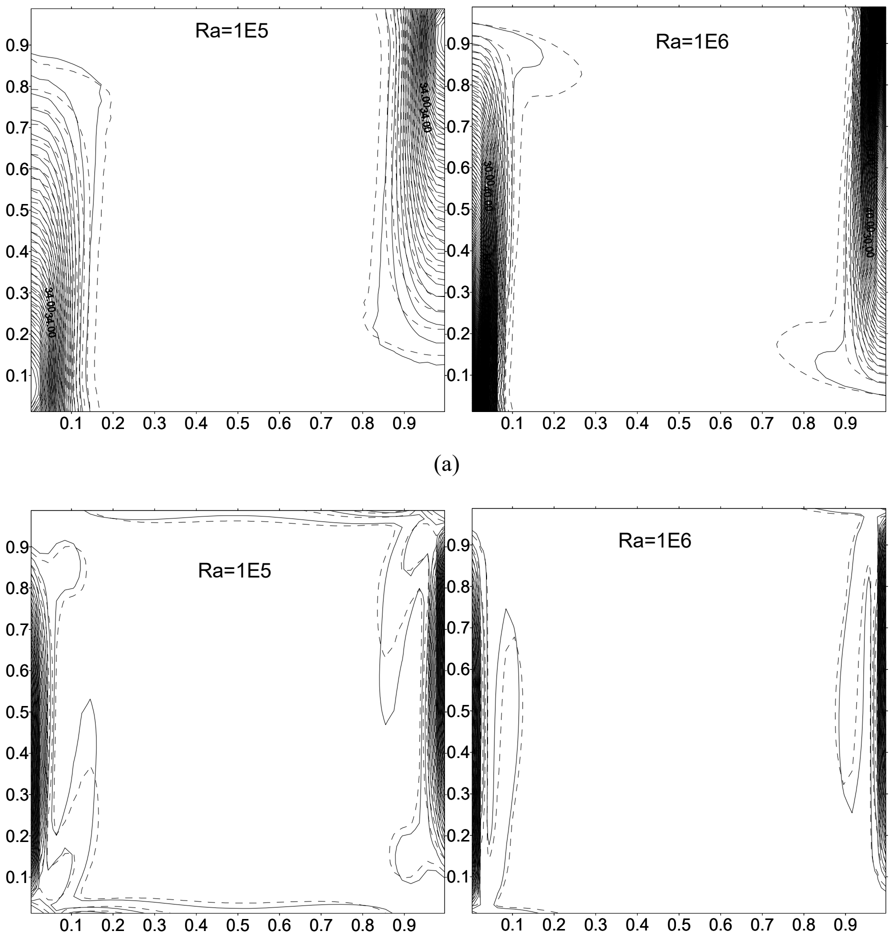


Fig. 6 Total entropy generation



(a)

(b)

Fig. 7 Contours of entropy generation (a) and fluid friction for irreversibility distribution ratio (b), for water (solid lines) and nanofluid with φ=5% (dashed lines) at T=20°C and different Ra

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The entropy generation maps due to heat transfer and fluid friction for irreversibility distribution ratio maps at T=20 °C are depicted in Fig. 7. It can be observed from this figure that the entropy generation maps due to heat transfer have symmetric and are concentrated along the left and right walls of cavity thanks to the existence of a temperature gradient between these two walls. In addition, we see a very clear dissimilarity between contours regarding the pure water and nanofluid.

VI. CONCLUSION

In this paper, a numerical work is performed to study the effect of adding nanoparticles in basic liquid on the heat transfer in a heated cavity, whereas entropy generation due to fluid friction and heat transfer at various Rayleigh numbers is analyzed. Al_2O_3–water nanofluid with different nanoparticle volume-fractions is compared to water for different temperature.

We investigate the natural convection in a cavity heated from vertical side. It appears that, at low temperature ($T \leq 40$ °C) the addition of solid particle Al_2O_3 into the pure water lead to a decrease in heat transfer and entropy generation, it is only at high temperature when heat transfer is enhanced by the addition of nanosolids into basic liquid. The augmentation of the heat transfer leads to an increase in the entropy generation. This situation is ideal for the operation of thermal solar systems such as solar water heater wherein the average water temperature is relatively high and can reach 80°C.

REFERENCES

[1] Choi SUS, Eastman JA (1995) "Enhancing thermal conductivity of fluids with nanoparticles," IntMechEng Cong Exp, ASME, FED 231/MD 66, pp. 99–105

[2] Nader Ben-Cheikh, Ali J. Chamkha, Brahim Ben-Beyaand Taieb Lili (2013), "Natural Convection of Water-Based Nanofluids in a Square Enclosure with Non-Uniform Heating of the Bottom Wall," Journal of Modern Physics, 4, pp. 147-159.

[3] Bouhalleb M. and Abbassi H. (2014) "Natural convection of nanofluids in enclosures with low aspect ratios," Int J Hydrogen Energ 39, pp. 15275-15286.

[4] Oztop F. H and Abu-Nada E (2008) "Numerical study of natural convection in partially heated rectangular enclosures filled with nanofluids," Int J Heat Fluid Fl 29, pp. 1326–1336.

[5] Ghasemi B. and Aminossadati M. S. (2009) "Natural convection heat transfer in an inclined enclosure filled with a water-Cu Onanofluid," Numer Heat Tr A-Appl 55, pp. 807-823.

[6] Arifin N. M, Nazar Rand PoP I. (2011) "Non-isobaric Marangoni boundary layer flow for Cu, Al2O3 and TiO2 nanoparticles in a water based fluid," Meccanica 46, pp. 833–843.

[7] Nasrin R, Alim M. A and Chamkha A. J (2012) "Buoyancy-driven heat transfer of water–Al_2O_3nanofluid in a closed chamber: Effects of solid volume fraction, Prandtl number and aspect ratio," Int J Heat Mass Tran 55, pp. 7355–7365.

[8] Saleh H, Roslan Rand Hashim I. (2011) "Natural convection heat transfer in a nanofluid-filled trapezoidal enclosure," International Journal of Heat and Mass Transfer, 54, pp. 194–201.

[9] Santra AK, Sen S and Chakraborty N. (2008), "Study of heat transfer characteristics of copper-water nanofluid in a differentially heated square cavity with different viscosity models," J Enhanced Heat Transf; 15(4), pp. 273–287.

[10] GH.R. Kefayati, S.F. Hosseinizadeh, M. Gorji and H. Sajjadi (2012) "Lattice Boltzmann simulation of natural convection in an open enclosure subjugated to water/copper nanofluid," International Journal of Thermal Sciences 52, pp. 91-101.

[11] G.A. Sheikhzadeh et al. (2011), "Natural convection of Cu–water nanofluid in a cavity with partially active side walls," European Journal of Mechanics B/Fluids 30, pp. 166–176.

[12] M. Magherbi, H. Abbassi and A. Ben Brahim (2003), "Entropy generation at the onset of natural convection," Int. J. Heat Mass Tran46, pp. 3441–3450.

[13] G.G. Ilis, M. Mobedi and B. Sunden (2008), "Effect of aspect ratio on entropy generation in a rectangular cavity with differentially heated vertical walls," Int. Commun. Heat Mass Trans35, pp. 696–703.

[14] Rejane De C. Oliveski, Mario H. Macagnan, Jacqueline B. Copetti (2009) "Entropy generation and natural convection in rectangular cavities," ApplThermEng 29, pp. 1417–1425.

[15] O. Mahian, A. Kianifar, C. Kleinstreuer, M.A. Al-Nimr, I. Pop, A.Z. Sahinand S. Wongwises (2013), "A review of entropy generation in nanofluid flow," Int. J. Heat Mass Tran 65, pp. 514–532.

[16] H.F. Oztop and K. Al-Salem "A review on entropy generation in natural and mixed convection heat transfer for energy systems" Renewable and Sustainable Energy Reviews 16 (2012), pp. 911– 920.

[17] F. Selimefendigil and H.F. Öztop (2015) "Natural convection and entropy generation of nanofluid filled cavity having different shaped obstacles under the influence of magnetic field and internal heat generation" Journal of the Taiwan Institute of Chemical Engineers 56, pp. 42–56.

[18] Ching-Chang Cho (2014), "Heat transfer and entropy generation of natural convection in nanofluid-filled square cavity with partially-heated wavy surface," Int. J. Heat Mass Tran 77, pp. 818–827.

[19] H. Saleh, R. Roslan and I. Hashim (2011) "Natural convection heat transfer in a nanofluid-filled trapezoidal enclosure," International Communications in Heat and Mass Transfer 38, pp. 972–983.

[20] Nguyen C, Desgranges F, Roy G, Galanis N, Mare T, Boucher Sand Mintsa A. H (2007) "Temperature and particle-size dependent viscosity data for water-based nanofluids – hysteresis phenomenon," Int J Heat Fluid Fl 28, pp. 1492–1506.

[21] Pastoriza G. M. J, Casanova C, Legido J. LandPiñeiro M. M (2011) "CuO in water nanofluid: influence of particle size and polydispersity on volumetric behaviour and viscosity," Fluid Phase Equilibr 300, pp. 188–196.

[22] Kulkarni D. P, Das D. K and Vajjha R.S (2009) "Application of nanofluids in heating buildings and reducing pollution," ApplEnerg 86, pp. 2566–2573.

[23] Teng T, Hung Y. H, Teng T. C, Mo H. E and Hsu H. G (2010) "The effect of alumina/water nanofluid particle size on thermal conductivity," ApplThermEng30, pp. 2213-2218.

[24] Li H, He Y, Hu Y, Jiang B and Huang Y (2015) "Thermophysical and natural convection characteristics of ethylene glycol and water mixture based ZnO nanofluids," Int J Heat Mass Tran 91, pp. 385–389.

[25] Brinkman H. C (1952) "The viscosity of concentrated suspensions and solution," JChemPhys 20, pp. 571-581.

[26] Batchelor G (1977) "The effect of Brownian motion on the bulk stress in a suspension of spherical particles," J Fluid Mech 83, pp. 97–117.

[27] Abu-Nada E, Masoud Z, Oztop H. F and Campo A (2010) "Effect of nanofluid variable properties on natural convection in enclosures," Int J Therm49, pp. 479–491.

[28] Khanafer K and Vafai K (2011) "A critical synthesis of thermophysical characteristics of nanofluids," Int J Heat Mass Tran 54:4410-4428.

[29] A. Bejan, "Entropy generation through heat and fluid flow", Wiley, NewYork,1982.

[30] Lai F, Yang Y (2011) "Lattice Boltzmann simulation of natural convection heat transfer of Al2O3/water nanofluids in a square enclosure," Int J ThermSci 50, pp. 1930-1941.

[31] Kahveci K (2010) "Buoyancy driven heat transfer of nanofluids in a tilted enclosure," J Heat Transf 132, pp. 062501-7.

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Open Science Index, Mechanical and Mechatronics Engineering Vol:10, No:12, 2016 publications.waset.org/10006066.pdf

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