Second law analysis in Cu-Water nanofluid in a cavity

with semicircular isothermal walls

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**Abstract**--**This work focuses on the influence of different parameters on the entropy generation and the Bejan number in a cavity filled with a Cu-Water nanofluid, with two semicircular isothermal walls associated to the vertical sides. This investigation was concerned the minimization of entropy generation when the semicircular isotherm walls were translated along the vertical sides. Nine combinations related to the location of the two isothermal semicircles were considered. In this context, the variations with the location of the active walls of the thermal irreversibility, the viscous irreversibility, the Bejan number and the ratio (Ri) were calculated, for two fixed values of both, Rayleigh number and volume fraction.**

**Keywords: entropy generation, nanofluid, natural convection, Bejan number, heat transfer**

1. Introduction

Many studies concerning nanofluid flow have been published. Abu-Nada and Ozotop [1] studied the effects of inclination angle on natural convection in enclosures filled with Cu-water nanofluid. Results indicate that the addition of copper nanoparticles has produced important enhancement on heat transfer compared to pure fluid. Heat transfer is enhanced with increasing Rayleigh number almost linearly but the effect of nanoparticles concentration on Nusselt Number is more pronounced at low Rayleigh number than at high Rayleigh number. Mahmoudi et al. [2] studied entropy generation due to natural convection in partially open cavity where the nanofluid is exposed to a thin heat source. They specified that when the open boundary is situated upwards, the fluid flow augments and hence the heat transfer and Nusselt number increase but the total entropy generation decreases. El Bouihi and Sehaqui [3] Studied natural convection in a two dimensional enclosure numerically with a sinusoidal boundary thermal condition using nanofluid. They determined that, the heat transfer rate increases when nanoparticles volume fraction increases and that, the pure water and the nanofluid have the same velocity profiles. Chen et al. [4] examined the total irreversibility in mixed convection flow of Al203-Water nanofluid within a vertical channel. They showed that, for a lower Brinkman number the local Nusselt number of the nanofluid on the hot wall is greater than that of pure water and increases with an increasing nanoparticle concentration. Shahi et al. [5] analyzed natural convection heat transfer and entropy generation in a square cavity protruding heat source. They observed that increasing nanoparticles volume fraction can reduce the entropy generation and increase the Nusselt number. Oliveski et al. [6] studied numerically the entropy generation on natural convection in rectangular cavities. They observed that the total entropy increases exponentially with the Rayleigh number and increases linearly with the aspect ratio and the irreversibility coefficient.. Patel et al. [7] studied a micro-convection model for thermal conductivity of nanofluids. They remarked a slight heat transfer enhancement of 0.8% with alumina particles suspended in water compared to Hamilton- crosser model. They supposed that an increase in a specific surface area as well as Brownian motion were the most significant reasons for anomalous enhancement in thermal conductivity of nanofluids.

To our knowledge, the use of the thermal conductivity model involving the micro-convection phenomenon to calculate the entropy generation of nanofluid flow in a cavity with two semicircular isothermal walls has not yet been encountered. The present paper reports a numerical study related to the effects of the Rayleigh number, the volume fraction, the powder size and the location of the active walls on the entropy generation, the Bejan number the thermal entropy generation ratio in steady state of natural convection.

**2.** Problem Statement

The studied system consists in a square cavity filled with Cu-Water nanofluid, with two isothermal semicircular walls linked to the vertical sides. The first one, maintained at high temperature, was associated to the left side. The second, maintained at cold temperature was associated to the right side. The remaining walls were insulated and adiabatic. The base fluid (water) and the copper nanoparticles (Cu) were supposed to be in thermal equilibrium. All physical properties of the nanofluid were assumed to be constant, except the density which satisfied the Boussinesq approximation. The characteristics of the base fluid and the solid nanoparticles are listed in Table I.

**Table I**: Physical properties of water and Cu

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Water**  **Cu** | ρ (Kg.m-3)  997.1  8933 | Cp (J.Kg-1.K-1)  4179  385 | K (W.m-1.K-1)  0.613  400 | ẞ (k-1)  2.1\*10-4  1.67\*10-5 |

**3. Mathematical formulation**

The governing equations can be written in dimensionless form as follows:

 (1)

 (2)

 (3)

 (4)

Here, we used the conductivity model of Patel et al. [7]. This model predicts the nanofluid thermal conductivity for nanoparticle size, volume fraction and temperature variation ranging from 10 to 100nm, from 1% to 8% and from 25°c to 50°c, respectively.. It presents a semi-empirical approach for the enhancement in thermal conductivity by emphasizing the increase in the specific area as well as the Brownian motion through the micro-convection. Based on this model, nanofluid thermal conductivity is written as:

 (5)

The parameter C is fixed and equal to 25000. The parameters Pe and (As/Af) are defined as:

 (6)

In Eq.(6), df is the molecular size of water, which is taken as 2A° and ds is the diameter of solid particles. The variable us, which depends on the temperature, is the Brownian motion velocity of particles and is given by [8]:

 Where kb is the Boltzmann constant.

4. Entropy generation

The entropy generation is given by the sum of conjugate fluxes and forces products. In natural convection process using the dimensionless parameters listed above, the dimensionless entropy generation expression becomes:

 (7)

According to the expressions of the Rayleigh number and the physical properties of the nanofluid mentioned above, the distribution irreversibility ratio can be written as:

 (8)

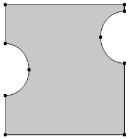
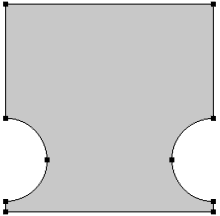
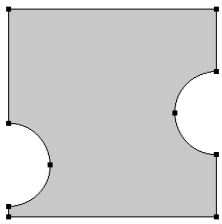
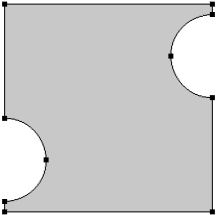
5. Numerical Procedure and Validation

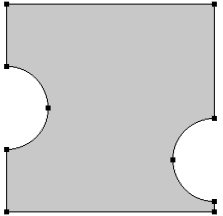
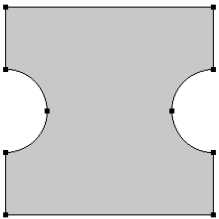
In the dimensionless form and taking into account the initial and the boundary conditions, the flow governing equations were solved using COMSOL software. Results given by COMSOL calculations were validated with the works of Magherbi et al. [10] in terms of isentropic lines related to a pure fluid (air) .

6. Results and Discussion

Particular interest is given to the impact of the active walls location on the entropy generation, the Bejan number and the flow structure. In this study the Prandtl number and the distribution irreversibility ratio were fixed at 6.02 and 10-5, respectively.

In this section the effects of the position of the hot and the cold semicircular walls on the irreversibility, the entropy generation ratio (Ri), the Bejan number and the flow structure were studied. These two semicircular active walls having nine possible geometric configurations of the cavity (Fig.1).

1**  2** 3**

4**  5 **

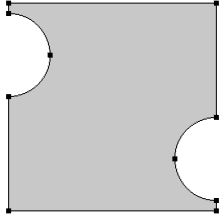
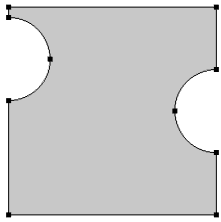
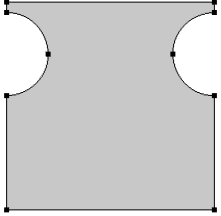
7**  8 **9 **

Figure1: Different geometric configurations of the cavity

Fig.2 shows the thermal entropy generation variation with these positions, for two values of both the Rayleigh number and the volume fraction. The location of the isothermal semicircular walls affects the irreversibility in the cavity. For Rayleigh number equal to 104, the thermal entropy generation is the highest for the 5th geometric configuration, whereas it is minimal for the 7th. The entropy generation is observable for all the geometric configurations. A Rayleigh number Ra=106, the minimum irreversibility remains related to configuration 7, but the maximum of thermal irreversibility is associated to configuration 2. It is important to note that, the volume fraction effect is more significant for the configuration where the irreversibility is maximum than for that where irreversibility is minimum. For example, at configuration 2 where irreversibility is maximum and for Ra=106, the entropy generation undergoes an increase of 14% when volume fraction increases from 0 to 8%. Whereas it undergoes an increase of 8.1% related to configuration7, where the irreversibility is minimum. For Ra=104 and 106 and for volume fraction equal to 0%, 4% and 8%.

Figure 2: Thermal entropy generation variation with the location of the isothermal semicircular walls for different volume fraction: a) Ra=104, b) Ra=106

As seen from Fig.3, the viscous irreversibility is maximum for configuration 3 and minimum for configuration 7. It is noticeable that, the effect of the volume fraction is considerable for the configuration where the viscous irreversibility is maximum, whereas it is nearly absent for the configurations where the viscous irreversibility is minimum. As important result, the impact of the nanoparticle

Figure 3: Viscous entropy generation variation with the location of the isothermal semicircular walls for different volume fraction: a) Ra=104, b) Ra=104

The variation of the thermal entropy generation ratio (Ri) with the location of the active semicircle walls is plotted in Fig.4. As can be seen from this figure, at fixed Rayleigh number, the ratio (Ri) is higher than the unity for all configurations, which implies that the heat transfer irreversibility in the nanofluid is greater than that in the base fluid for all the studied configurations and for the two concerned volume fractions. It is important to note that the ratio (Ri) is maximum for configuration 7, for which the thermal irreversibility in the base fluid is minimum. This leads ²to believe in the important impact of nanoparticles adding on the thermal irreversibility for this geometric configuration.

Figure 4: Variation of the thermal irreversibility ratio (Ri) with the location of the isothermal walls for different volume fraction: a) Ra=104; b) Ra=106

The variation of the Bejan number with the location of the active semicircle walls is given in Fig.5. As seen from the Fig.5a, for Rayleigh number equal to104, the Bejan number is higher than 0.9 and therefore thermal irreversibility strongly dominates for all the considered locations of the two semicircles. It is noticeable that, although its variation is small, the Bejan number presents a maximum and a minimum for configurations 7 and 3, respectively. For the Rayleigh number equal to 106 the Bejan number takes a value greater than 0.5 for configuration 7 only (Fig.5b). Consequently, for this geometric configuration, the thermal irreversibility dominates. Otherwise, the viscous irreversibility is the most dominant for all the remaining configurations. Itis important to notice from Fig.6b that, whenthe volume fraction increases, the thermal and the viscous ? and 8, since the Bejan number approaches the value of 0.5.

Figure5 : Bejan number as function of the location of the isothermal walls for different volume fraction: a) Ra=104; b) Ra=106

**7.** Conclusion

Based on this study, the following results can be drawn:

1. The minimum thermal irreversibility corresponds to the geometric configuration 7 for all Rayleigh number. The maximum thermal irreversibility corresponds to configurations 5 and 2 for Ra=104 and 106, respectively.
2. For Rayleigh number equal to104, the thermal irreversibility strongly dominates for all the considered configurations. For the Rayleigh number equal to 106, the thermal irreversibility dominates only for configuration 7.

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