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Simulation of Nanofluid in L-Shaped Cavities Using COMSOL

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Abstract: The free convection flow of nanofluid in L-shaped cavities has been conducted in this study. The aim of this study is to simulate nanofluid flows in L-shaped cavities using a software, COMSOL Multiphysics. COMSOL Multiphysics 6.0 was chosen to provide an appropriate guidance in solving mathematics modelling to demonstrate the impacts of the Rayleigh number, aspect ratio of the L-shaped cavity, and volume fraction of the Copper nano0particles on the flow and thermal fields and heat transfer inside the cavity. The cavity's left and right walls are kept at a constant temperature, while its top and bottom walls are insulated. Furthermore, it is discovered that the rate of heat transfer increases as the aspect ratio of the cavity decreases.

Keywords: Nanofluid, L-Shaped Cavities, COMSOL

1. Introduction

Convection flow fluid flow heat transfer is a common form of heat transfer used in variety of industrial operations such as electronic device cooling, reactor insulating, home ventilation, and solar collectors [1]. Nanofluids have the potential to be the solution of heat transfer fluids in a variety of heat transfer applications [2]. According to the research by [3] on numerical simulation of free convection of a nanofluid in L-shaped cavities, the rate of increase of the average Nusselt number with increase in the volume fraction of nanoparticles is higher for the L-shaped cavities with lower aspect ratio. In the existing study, the finite volume method and SIMPLER algorithm were used to discretize the governing equations.

COMSOL Multiphysics will be used in this thesis to solve the dimensionless governing equations provided by [3] and free convection fluid flow and nanofluid heat transfer in this problem will be processed using COMSOL for future analysis. The purpose of COMSOL is to deliver simple software solutions to engineering challenges and to assist their users in getting the most out of their products [4].

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2. Methodology

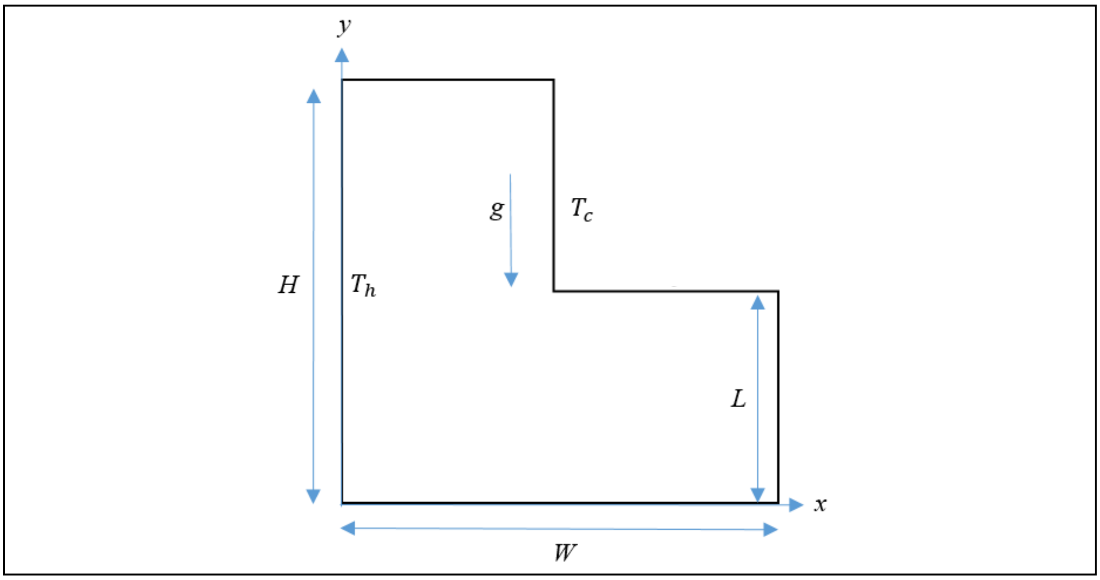


Figure 1: A schematic representation of the L-shaped cavity used in the simulation of nanofluid in L-shaped cavities [3]

Based on Figure 1, the height and the width of the cavity are stated as H and W respectively where height, H is equally to width, W. L is the thickness of the cavity, and meanwhile the aspect ratio of the cavity is stated as LH. Meanwhile, g stands for gravitational acceleration. T_h and T_c are dimensional temperature where h is hot, and c is cold.

2.1 Governing Equation

The following are the continuity, momentum, and energy equations that control two-dimensional laminar free convection with the Boussinesq approximation in the y-direction.

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0\,, \qquad Eq.1$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\rho_{nf}}\frac{\partial p}{\partial x}+\frac{\mu_{nf}}{\rho_{nf}}\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right), \qquad Eq.2$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\rho_{nf}}\frac{\partial p}{\partial x}+\frac{\mu_{nf}}{\rho_{nf}}\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)+\frac{(\rho\beta)_{nf}}{\rho_{nf}}g(T-T_c)\,, \qquad Eq.3$$

and

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha_{nf}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right), \qquad Eq.4$$

Where ρ is the density, C_p is heat capacity, β is thermal expansion coefficient, and α is thermal diffusivity of the nanofluid are as following, respectively,

$$\rho_{nf}=(1-|\varphi)\rho_f+\varphi\rho_s\,, \qquad Eq.5$$

$$(\rho C_p)_{nf}=(1-|\varphi)(\rho C_p)_f+\varphi(\rho C_p)_s\,, \qquad Eq.6$$

$$(\rho\beta)_{nf} = (1 - |\varphi)(\rho\beta)_f + \varphi(\rho\beta)_s\,, \qquad Eq.7$$

$$\alpha_{nf} = \frac{k_{nf}}{(\rho C_p)_{nf}}\,. \qquad Eq.8$$

The Brinkman model is used to calculate the effective dynamic viscosity of the Cu-water nanofluid (Brinkman, 1952) [5],

$$\mu_{eff} = \frac{\mu_f}{(1 - |\varphi)^{2.5}}\,. \qquad Eq.9$$

The Maxwell model is used to calculate the effective thermal conductivity of the nanofluid (J., 1904) [6],

$$\frac{k_{nf}}{k_f} = \frac{(k_s + 2k_f) - 2\varphi(k_f - k_s)}{(k_f + 2k_s) - \varphi(k_f - k_s)}\,. \qquad Eq.20$$

The dimensionless parameters defined below are used to convert the governing equations $Eq.1$ to $Eq.4$ into dimensionless form.

$$X = \frac{x}{H}, \qquad Y = \frac{y}{H}, \qquad U = \frac{uH}{\alpha_f}, \qquad V = \frac{vH}{\alpha_f}, \qquad P = \frac{pH^2}{\rho_{nf}\ \alpha_f^2}, \qquad \theta = \frac{T - T_c}{T_h - T_c}. \qquad Eq.31$$

The dimensionless forms of the governing equations (1) to (4) are given by

$$\frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} = 0\,, \qquad Eq.42$$

$$U\frac{\partial U}{\partial X} + v\frac{\partial U}{\partial Y} = -\frac{\partial P}{\partial X} + \frac{\mu_{nf}}{\rho_{nf}}\left(\frac{\partial^2 U}{\partial X^2} + \frac{\partial^2 U}{\partial Y^2}\right), \qquad Eq.53$$

$$U\frac{\partial U}{\partial X} + v\frac{\partial U}{\partial Y} = -\frac{\partial P}{\partial Y} + \frac{\mu_{nf}}{\rho_{nf}}\left(\frac{\partial^2 V}{\partial X^2} + \frac{\partial^2 V}{\partial Y^2}\right) + \frac{(\rho\beta)_{nf}}{\rho_{nf}\ \beta_f} Ra\,\mathrm{Pr}\,\theta\ , \qquad Eq.64$$

$$u\frac{\partial \theta}{\partial X} + v\frac{\partial \theta}{\partial Y} = \frac{\alpha_{nf}}{\alpha_f}\left(\frac{\partial^2 \theta}{\partial X^2} + \frac{\partial^2 \theta}{\partial Y^2}\right), \qquad Eq.75$$

where the Rayleigh number *Ra*, and the Prandtl number *Pr* are defined as

$$Ra = \frac{g\beta_f(T_h - T_c)H^3}{\alpha_f v_f}, \qquad Pr = \frac{v_f}{\alpha_f}\,. \qquad Eq.86$$

2.2 COMSOL Multiphysics Simulation

Figure 2 shows the flow chart on how to use COMSOL in solving the problem of nanofluid in L-shaped cavities. At the end of the processes, the results will obtain.

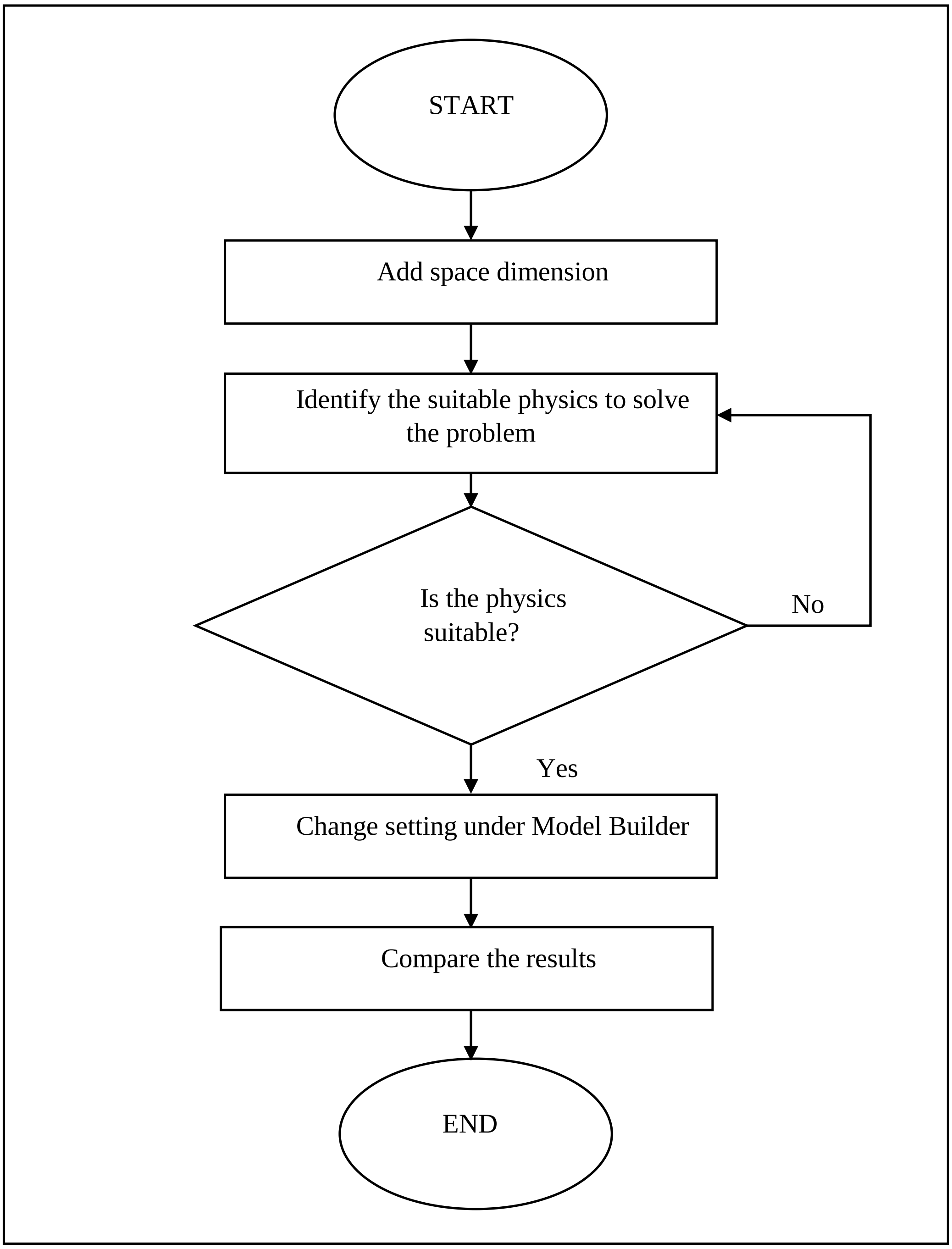


Figure 2: Flow chart in using COMSOL [4]

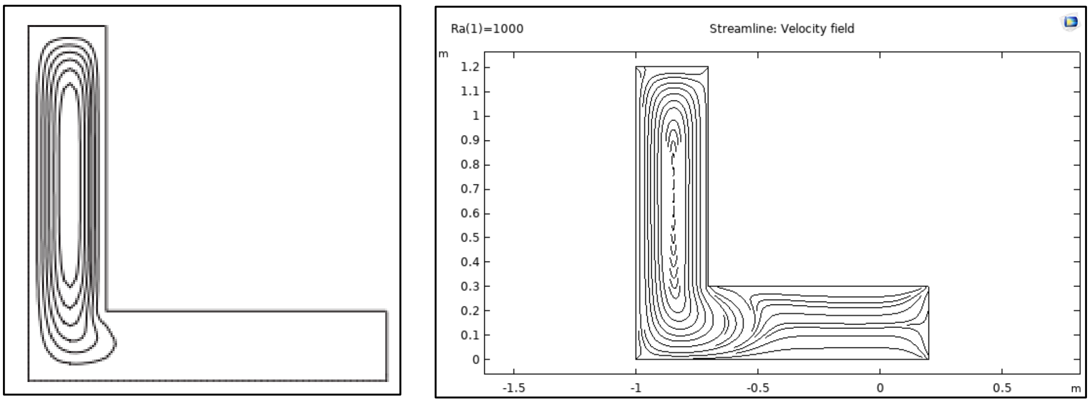
3. Results and Discussion

This section focused on the simulation of nanofluid in L-shaped cavities as the problem, which was resolved using COMSOL Multiphysics version 6.0. This chapter compares the COMSOL results to the preceding study. The streamlines and velocity magnitude are two different results that are presented in this section.

3.1 Streamlines

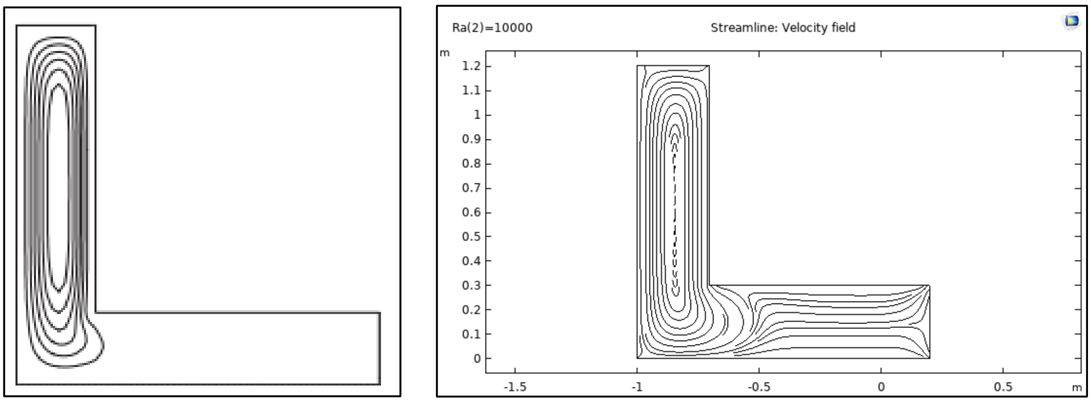
The models repeatedly solve the problem of buoyant flow in L-shaped cavities. It investigates temperature field and convective flow rates caused by fluid properties, cavity size, and heat decreases.

Using nondimensional parameters and a Boussinesq term for the buoyant drive with the Laminar Flow and Heat Transfer in Fluids interfaces, the iterative approach is optimised for a quick, efficient solution.



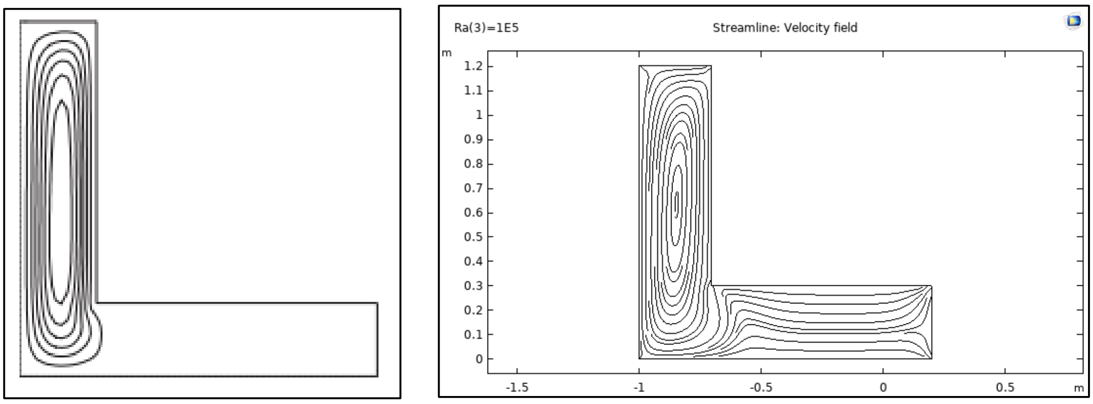
(a) (b)

Figure 3: Streamlines for (a) Ra = 10^3 from previous study by [3] and (b) using COMSOL, Cavity aspect ratio = 0.2



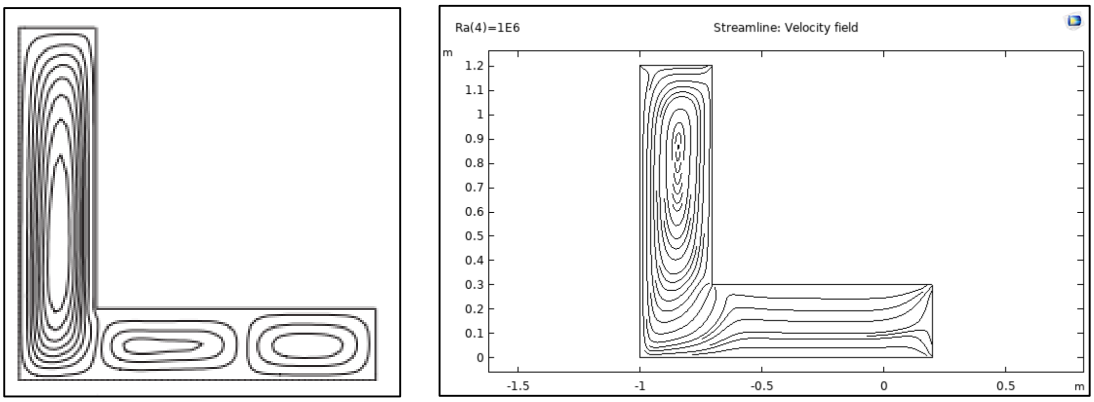
(a) (b)

Figure 4: Streamlines for (a) Ra = 10^4 from previous study by [3] and (b) using COMSOL, Cavity aspect ratio = 0.2



(a) (b)

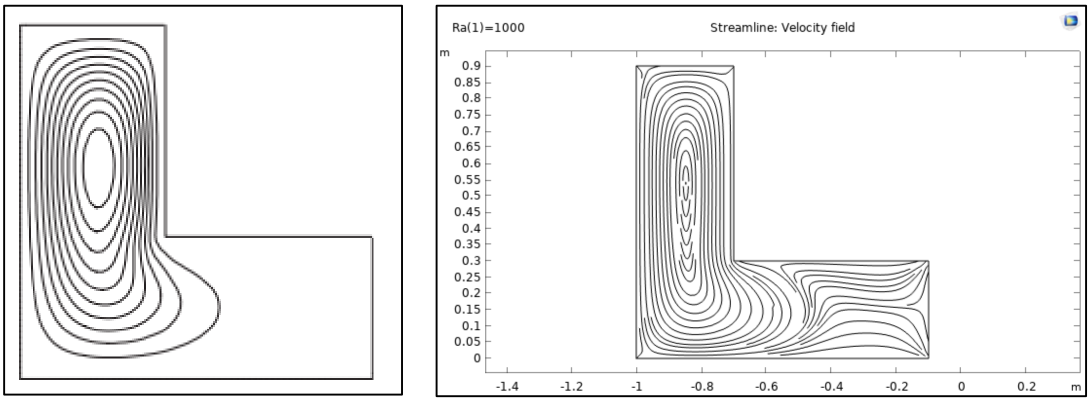
Figure 5: Streamlines for (a) Ra = 10^5 from previous study by [3] and (b) using COMSOL, Cavity aspect ratio = 0.2



(a) (b)

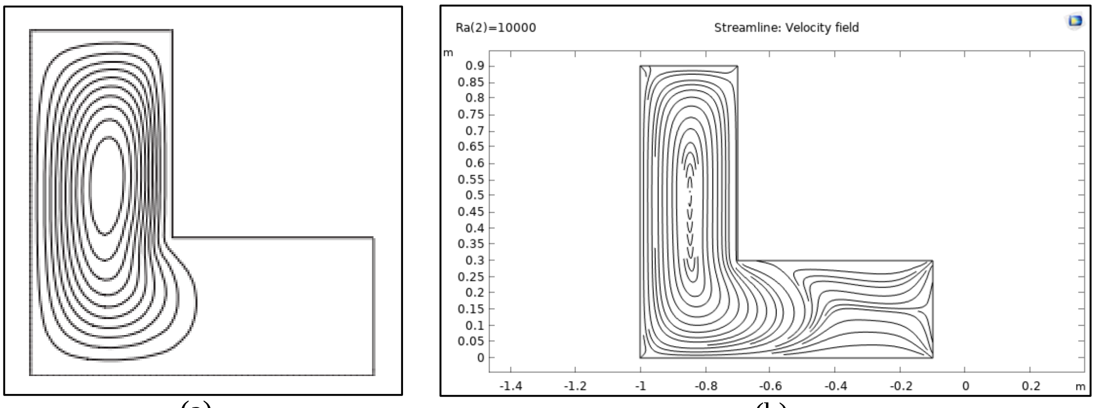
Figure 6: Streamlines for (a) Ra = 10^6 from previous study by [3] and (b) using COMSOL, Cavity aspect ratio = 0.2

Figure 3 to 6 shows the streamlines from the previous study by Mahmoodi (2011) and the result for the present study computed by COMSOL respectively. When *Ra* =10^3, the flow of the streamlines shows that a single eddy forms inside the vertical part of the hollow. Eddy is a current of liquid or gas running contrary to the main current. In this study, eddy is considered as liquid phase. At this Rayleigh number range, heated fluid ascends near the hot vertical walls, then cools and lowers near the cold vertical walls, forming a single clockwise eddy. The flow in the cavity's horizontal section is nearly stationary. Because of the Prandtl number used, the cavity inside the horizontal part is not the same as in previous studies.



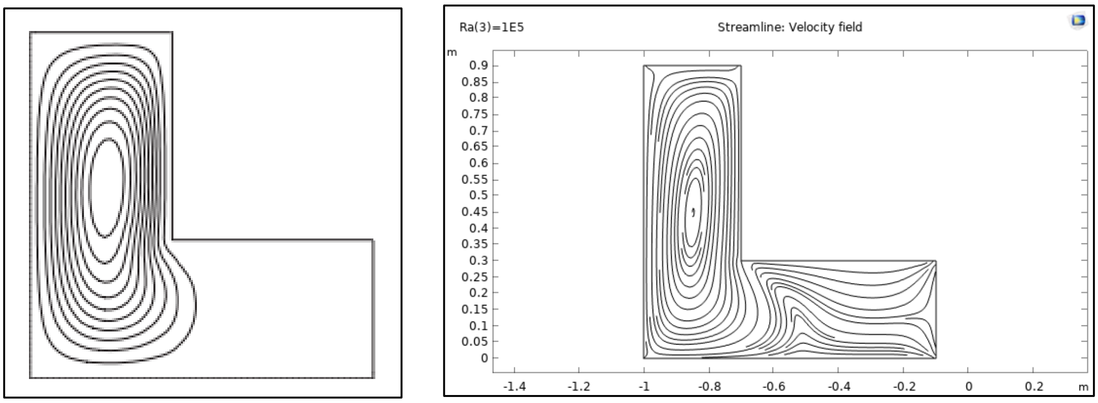
(a) (b)

Figure 7: Streamlines for (a) Ra = 10^3 from previous study by [3] and (b) using COMSOL, Cavity aspect ratio = 0.4.



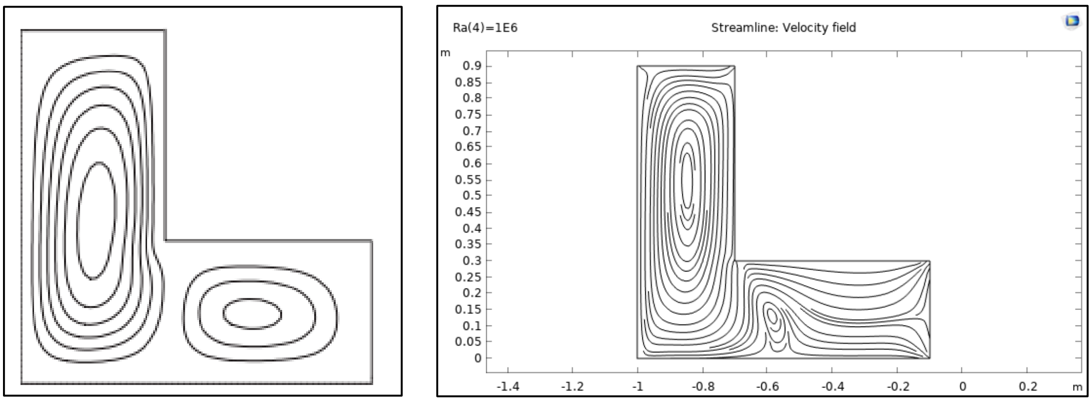
(a) (b)

Figure 8: Streamlines for (a) Ra = 10^4 from previous study by [3] and (b) using COMSOL, Cavity aspect ratio = 0.4



(a) (b)

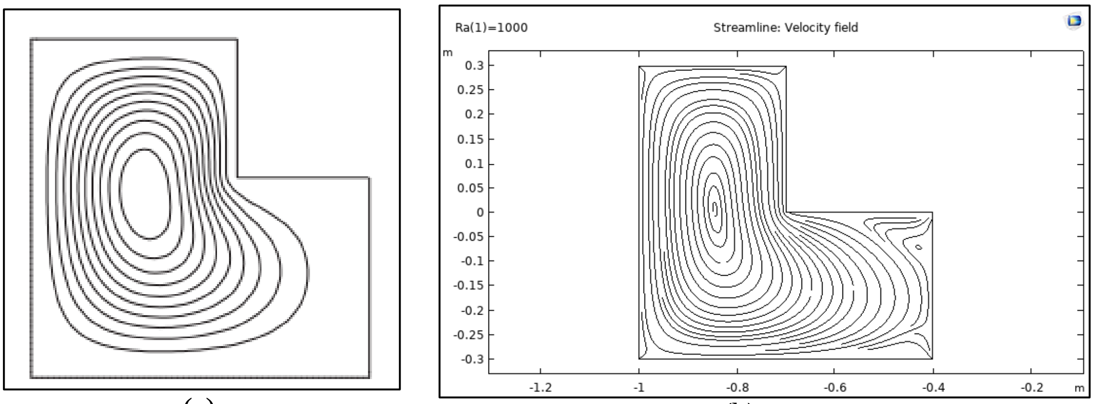
Figure 9: Streamlines for (a) Ra = 10^5 from previous study by [3] and (b) using COMSOL, Cavity aspect ratio = 0.4



(a) (b)

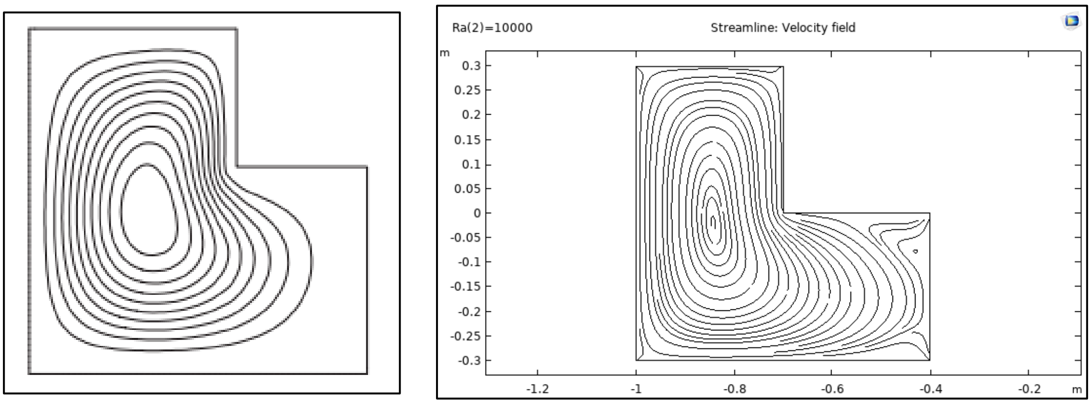
Figure 10: Streamlines for (a) Ra = 10^6 from previous study by [3] and (b) using COMSOL, Cavity aspect ratio = 0.4

Figure 7 to 10 shows the streamlines from the previous study by Mahmoodi (2011) and the result for the present study computed by COMSOL respectively. It shows that the Rayleigh number, increases from for (a) Ra = 10^3 to10^6, the vortices travel closer to the hot and cold walls. As a result, as the Rayleigh number increases from 10^5 to 10^6, the dominant heat transmission method shifts from conduction to convection. Figures 4.3 and 4.4 illustrate streamlines inside the cavity aspect rattio = 0.4 at various Rayleigh numbers and solid volume fractions of the nanofluid. As illustrated by the streamlines in Figure 7, for pure fluid at Ra =10^3, a single eddy forms inside the vertical part of the cavity, while the fluid in the horizontal part of the cavity is approximately stagnant. The cavity inside the horizontal part is not the same as previous study because of the Prandtl number.



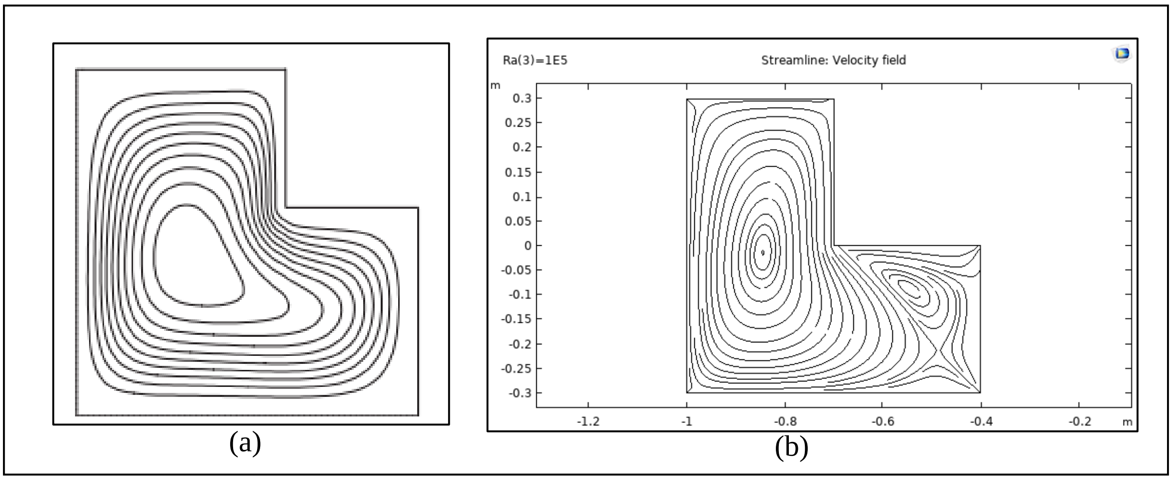
(a) (b)

Figure 11: Streamlines for (a) Ra = 10^3 from previous study by [3] and (b) using COMSOL, Cavity aspect ratio = 0.6



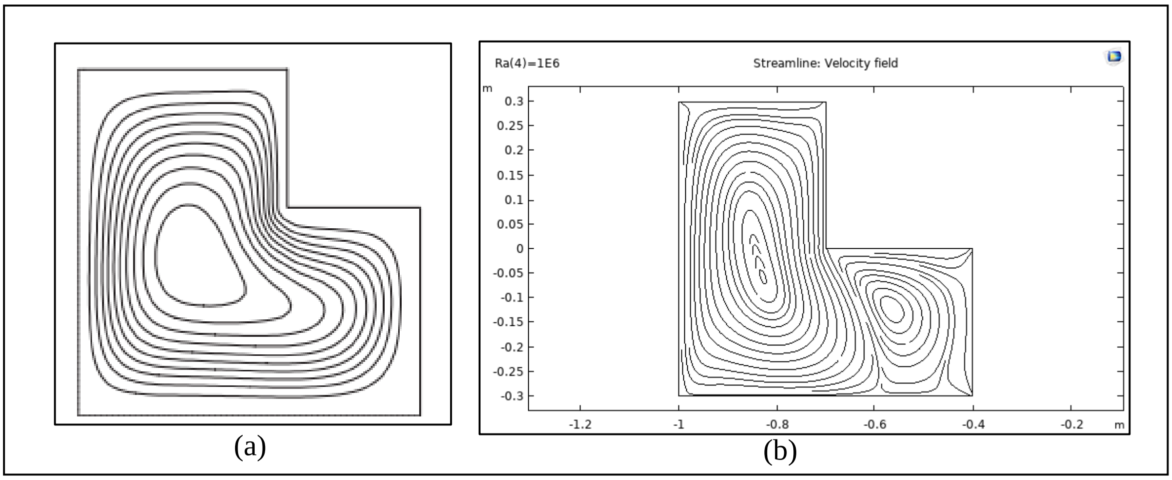
(a) (b)

Figure 12: Streamlines for (a) Ra = 10^4 from previous study by [3] and (b) using COMSOL, Cavity aspect ratio = 0.6



(a) (b)

Figure 13: Streamlines for (a) Ra = 10^5 from previous study by [3] and (b) using COMSOL, Cavity aspect ratio = 0.6



(a) (b)

Figure 14: Streamlines for (a) Ra = 10^6 from previous study by [3] and (b) using COMSOL, Cavity aspect ratio = 0.6

Figure 11 to 14 shows the streamlines from the previous study by [3] and the result for the present study computed by COMSOL respectively. Variation of streamlines with the Rayleigh number and the solid volume fraction of the nanofluid inside the L-shaped cavity aspect ratio = 0.6 is shown. At $Ra = 10^3$, when the cavity is filled with pure fluid, a single eddy is generated inside the cavity, with an elliptic-shaped core in the upper half of the vertical part of the cavity, as illustrated in Figure 11. The occupied portion of the cavity with the eddy grows as the Rayleigh number climbs from 10^3 to 10^6. A similar trend in streamlines is found for all values of the solid volume fraction of the nanofluid over this range of Rayleigh numbers. When the cavity is filled with pure fluid at $Ra = 10^6$, two fully developed clockwise spinning secondary eddies are detected inside a primary big eddy, and the secondary eddies merge as the solid volume fraction of the nanofluid increases.

4. Conclusion

In a nutshell, the simulation of nanofluid in L-shaped cavities has been achieved by using COMSOL Multiphysics 6.0. COMSOL Multiphysics 6.0 is utilized to handle the problem of nanofluid in L-shaped cavities with a magnetic field present. COMSOL is a program that solves problems using partial differential equations. It differs from the finite volume technique and staggered grid scheme employed in previous research by [3]. In conclusion, as Rayleigh number increases, viscous forces decrease in importance. The crossover point from conduction to convection is delayed to greater Rayleigh numbers when the aspect ratio of the cavity decreases. In comparison to existing study, the

COMSOL results only displayed the prominent part of the streamline. The portion with a very small value will not appear in the diagram because the source input for each software differs, the result from each software may differ.

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