Organisation of Islamic Cooperation

Numerical Investigation of Natural Convection in a Cube filled with Nanofluid

A THESIS SUBMITTED TO THE DEPARTMENT OF MECHANICAL AND CHEMICAL
ENGINEERING (MCE), ISLAMIC UNIVERSITY OF TECHNOLOGY

IN THE PARTIAL FULFILLMENT OF THE REQUIREMENT FOR DEGREE OF BACHELOR IN
SCIENCE IN MECHANICAL ENGINEERING

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ACKNOWLEDGMENTS

I would like to express my heartiest gratitude to Almighty Allah for his countless blessing, which enabled me to complete this thesis successfully. It is my pleasure to express my sincere gratitude to my project supervisor Dr. A. K. M. Sadrul Islam, Department of Mechanical and Chemical Engineering, Islamic University of Technology (IUT) for his constant support, guidance, helpful suggestions and supervision at all stages of this research work. The supervisor had dedicated his valuable time, even at odd hours, which had ensured the completion of this project. I also like to express my gratitude to my CFD Instructor Md. Hamidur Rahman, Department of Mechanical and Chemical Engineering, IUT for teaching me all the basics of Computational Fluid Dynamics (CFD) and helping me go through all the tough simulations and necessary tutorials. Lastly, I like to express my sincere gratefulness to Dr. Md. Abdur Razzaq Akhanda, Head of Department, Mechanical and Chemical Engineering, IUT for providing us all sorts of support. Special thanks go to my beloved parents whose love and inspiration kept me going during this project work.

I am greatly indebted to the above mentioned persons and without their encouragement it would have been impossible to complete this project work.

INDEX

CONTENTS PAGE

ABSTRACT

In this project, natural convective heat transfer in a partitioned cube utilizing nanofluids is studied. The vertical left and right walls are considered as the hot and cold walls, respectively and the partitions assumed to be adiabatic. The nanofluid used in this study is Al2O3 with the volume fraction of 20%. It is assumed that nanofluid is a single phase fluid. CFX and FLUENT 12.1.2 is used to simulate the problem. The influence of different parameters such as Rayleigh’s number (Ra=105 and 107), height of partition (h=0.1, 0.3, 0.5) at a fixed distance from the walls are studied. According to the results, Rayleigh’s number and height of the partition are important factors that extremely affect the streamlines and isotherms. At Ra=107, the flow is confined in the distance between walls and partitions. Furthermore, at high partitions, the isotherms are horizontal between two partitions. For a fixed amount of the partition height, Nusselt number increases as the Rayleigh number rises. On the other hand, for a fixed Rayleigh, with the increasing partition height, Nusselt number decreases along the hot wall.

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INTRODUCTION

Today more than ever, ultra-high-performance heat transfer plays an important role in the development of energy-efficient heat-transfer fluids required in many industries and commercial applications. However, conventional heat-transfer fluids (e.g. water, oil or ethylene glycol) are inherently poor heat transfer fluids. Nanofluid, a term coined by Choi in 1995, is a new class of heat-transfer fluids developed by suspending nanoparticles, such as small amounts of metal, non-metal or nanotubes in the fluids. The goal of nanofluids is to achieve the highest possible thermal properties at the smallest possible volume concentrations with a uniform dispersion and a stable suspension of nanoparticles in host fluids.

Buoyancy-induced flow and heat transfer is an important phenomenon used in various engineering systems. Some applications are solar thermal receivers, vapour absorption refrigerator units and electronic cooling, selective laser melting processes etc. Several researchers have been focused on numerical modeling of such flows. Oztop and Abu-Nada studied the two dimensional natural convection of various nanofluids in partially heated rectangular cavities and reported that the type of nanofluid is the key factor for a heat-transfer enhancement. They obtained the best results with Cu nanoparticles. Hwang et al studied natural convection of a water-based Al2O3 nanofluid in a rectangular cavity heated from below. They investigated the convective instability of the flow and heat transfer and reported that the natural convection of the nanofluid becomes more stable when the volume fraction of nanoparticles increases. Ho et al.6 studied the effects on the nanofluid heat transfer caused by viscosity and thermal conductivity in a buoyant enclosure. They demonstrated that the usage of different models for viscosity and thermal conductivity has a major impact on the heat transfer and flow characteristics.

The effect of the inclination angle on the heat transfer enhancement under natural convection has been studied by Oztop et al.7 (for water-based Al_2O_3 and TiO_2 nanofluids) and by Abu-Nada and Oztop (for water based Cu nanofluids). They reported that the effect of the inclination angle on the percentage of a heat-transfer enhancement becomes insignificant at a low Rayleigh number, but it decreases the enhancement of heat transfer with a nanofluid. Last but not least, the inclination angle is reported to be a good control parameter for both pure and nanofluid-filled enclosures.

Although quite some work has been done in this area, it is still safe to conclude that there is a lack of numerical studies of the heat characteristics of the nanofluids containing Al_2O_3 nanoparticles. The present work is therefore directed to study the natural convection heat-transfer characteristics of the water-based Au nanofluids for the Rayleigh number in the range of 103 ≤ Ra ≤ 105 and for the volume fraction of 0 ≤ φ ≤ 0.2

GOVERNING PARAMETERS

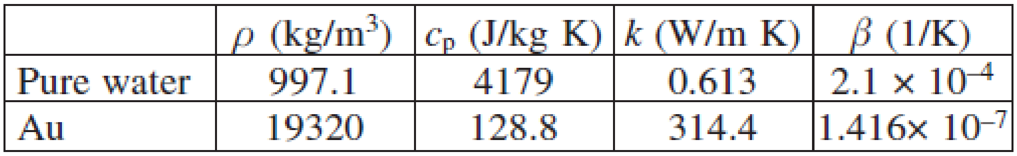
Density (ρ)

Thermal conductivity (K)

Dynamic Viscosity (ν)

Thermal Expansion (β)

Heat Capacitance (Cp)

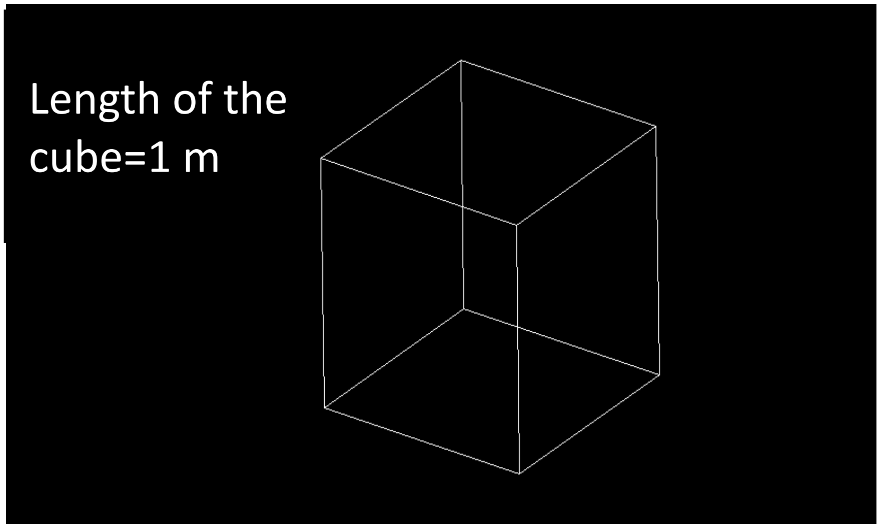


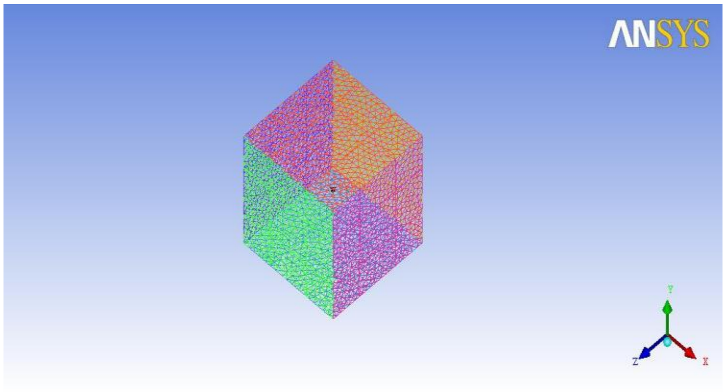
	ρ (kg/m^3)	c_p (J/kg K)	k (W/m K)	β (1/K)
Pure water	997.1	4179	0.613	2.1×10^{-4}
Au	19320	128.8	314.4	1.416×10^{-7}

Table 1: Thermo-physical properties of the Au nanofluid

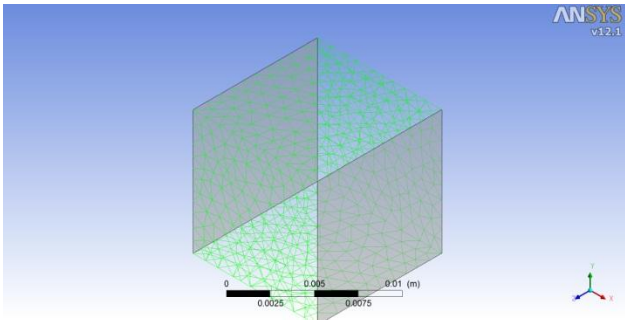
GEOMETRY, MESHINGAND BOUNDARY CONDITIONS

For drawing the geometry AutoCAD 2007 was used. Here is the figure of Geometry drawn:





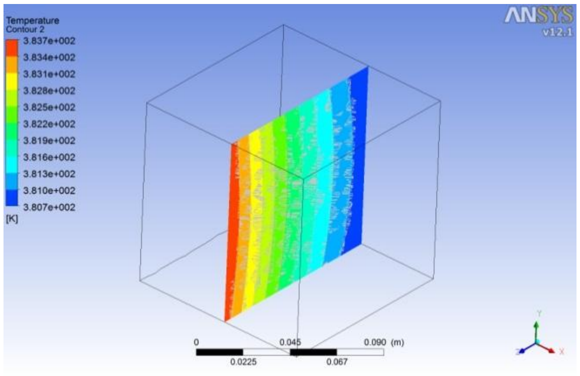
The simulation domain and the expected temperature distribution are shown schematically in Figure 1. The two vertical walls of the Cube enclosure are kept at different constant temperatures (TH – TC), whereas the other boundaries are considered to be isothermal in nature. Both velocity components are identically zero on each boundary because of the no-slip condition and impenetrability of the rigid boundaries. The temperatures for cold and hot vertical walls are specified. The isothermal temperature boundary conditions for the horizontal insulated boundaries are taken by 25 °C.

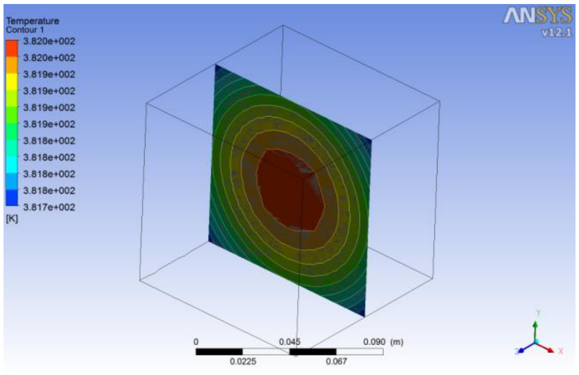


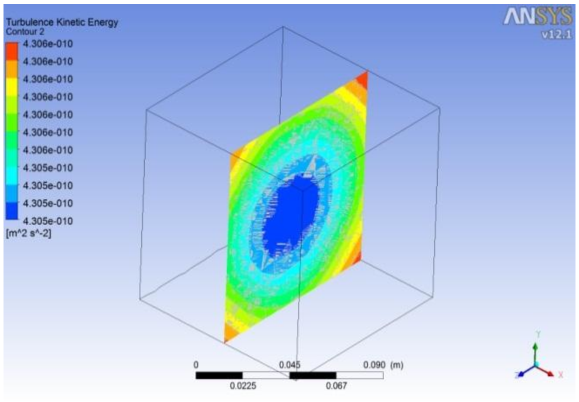
In the present study, the heat-transfer rates (along the hot vertical wall) in a cubic enclosure (of the dimension L), with differentially heated side walls, filled with Al2O3 nanofluid are expressed in terms of the local and mean Nusselt number and compared with the heat-transfer rate obtained in the case of pure water (φ = 0) with the same nominal Rayleigh number. Here the Rayleigh number Ra represents the ratio of the strengths of the thermal transports due to buoyancy to the thermal diffusion.

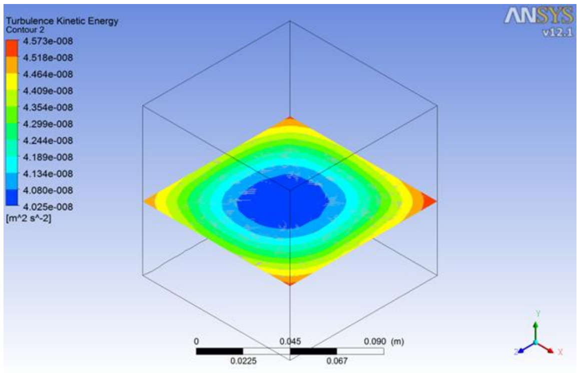
CFD-POST

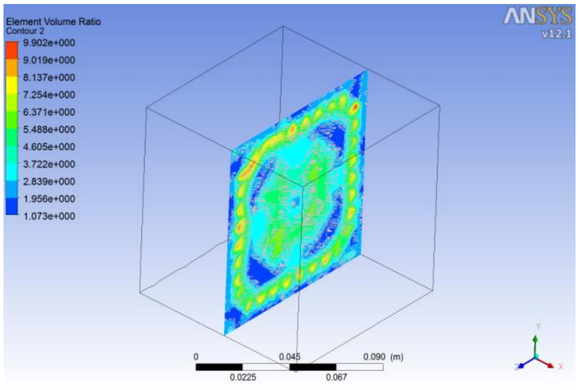
Here are some of the contours which were taken at different planes of different parameters:

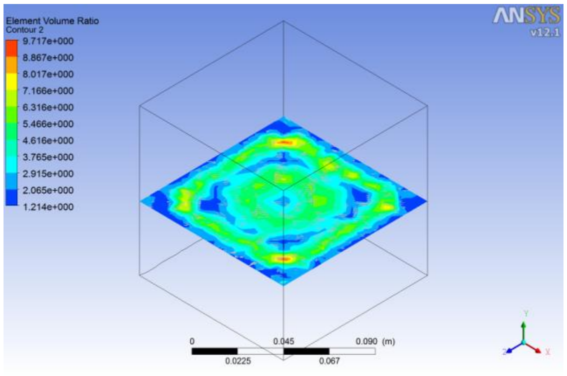


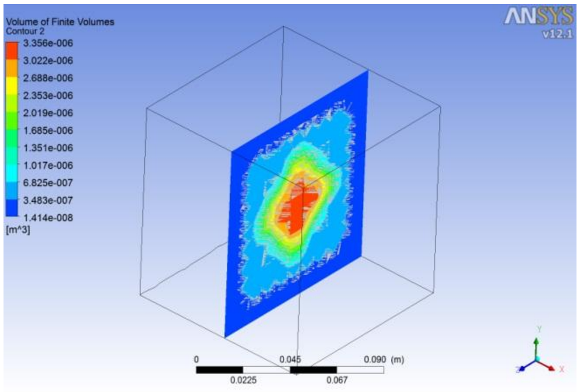











Volume of Finite Volumes
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3.022e-006
2.688e-006
2.353e-006
2.019e-006
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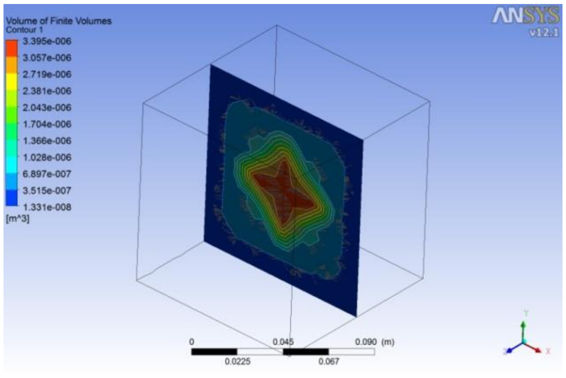
1.351e-006
1.017e-006
6.825e-007
3.483e-007
1.414e-008
[m^3]
ANSYS
v12.1
0
0.045
0.090 (m)
0.0225
0.067
Y
X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2.043e-006
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1.366e-006
1.028e-006
6.897e-007
3.515e-007
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[m^3]
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v12.1
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0.067
Y
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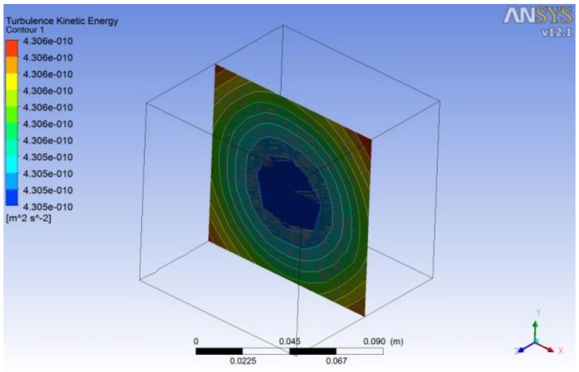
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4.306e-010
4.306e-010
4.306e-010
4.306e-010
4.306e-010
4.306e-010
4.305e-010
4.305e-010
4.305e-010
4.305e-010
[m^2 s^-2]
ANSYS
v12.1
0
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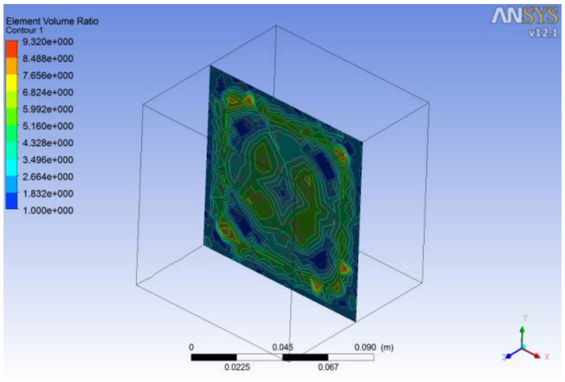
0.090 (m)
0.0225
0.067
Y
X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6.824e+000
5.992e+000
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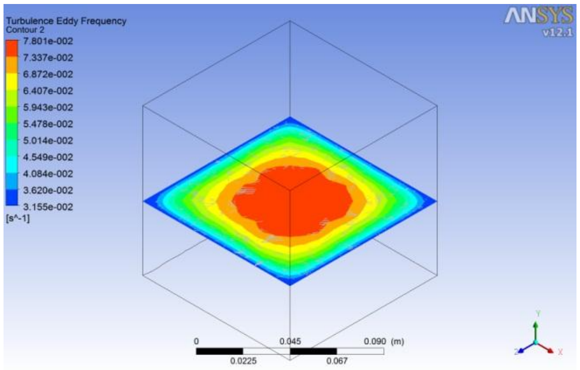
4.328e+000
3.496e+000
2.664e+000
1.832e+000
1.000e+000
ANSYS
v12.1
0
0.045
0.090 (m)
0.0225
0.067
Y
X


Turbulence Eddy Frequency
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7.337e-002
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6.407e-002
5.943e-002
5.478e-002
5.014e-002
4.549e-002
4.084e-002
3.620e-002
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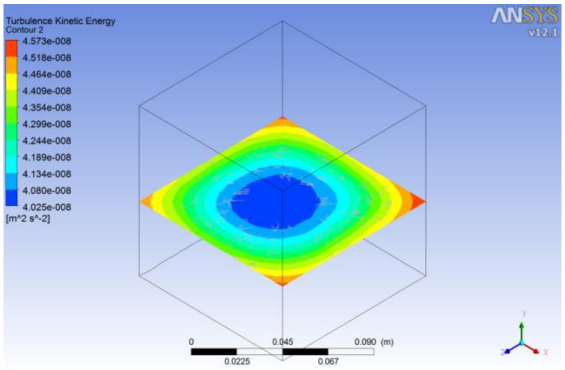
[s^-1]
ANSYS
v12.1
0
0.045
0.090 (m)
0.0225
0.067
Y
X


Turbulence Kinetic Energy
Contour 2
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4.464e-008
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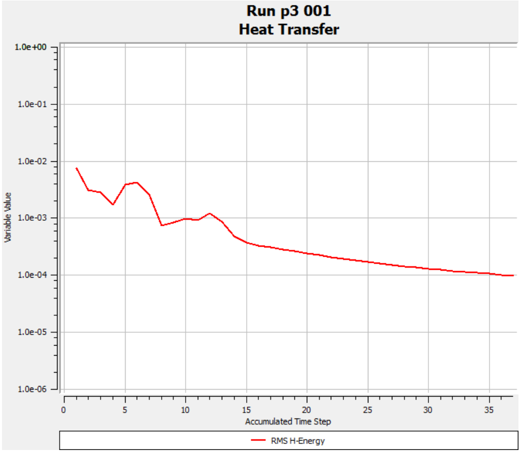
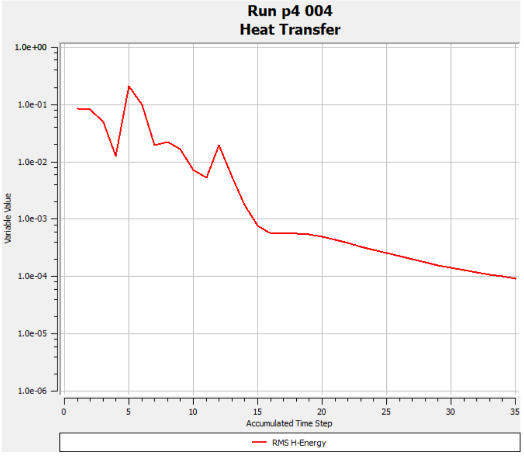
4.354e-008
4.299e-008
4.244e-008
4.189e-008
4.134e-008
4.080e-008
4.025e-008
[m^2 s^-2]
ANSYS
v12.1
0
0.045
0.090 (m)
0.0225
0.067
Y
X

RESULTS AND DISCUSSIONS



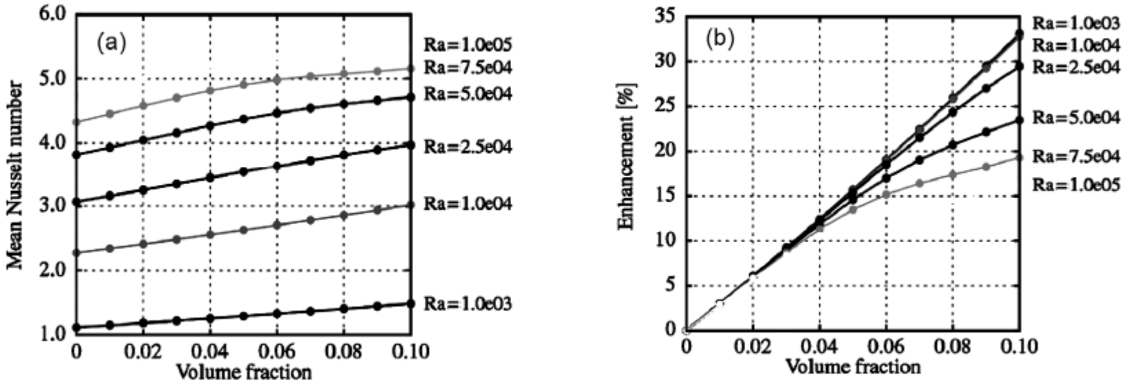
For water



For Al2O3

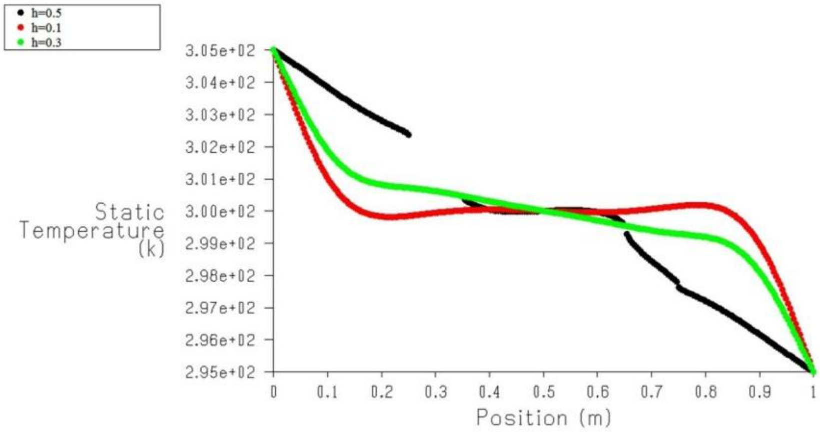
1. After simulating in the CFX-PRE we can obtain graphs of heat transfer. Comparing the above two cases we can see that the heat transfer rate is significantly increased in the latter case.

2. The variation of the mean Nusselt number along the hot wall with a solid volume fraction is shown in the next figure indicating that Nu increases with an increasing φ. For Ra ≤ 104, where the heat transfer is conduction dominated, the distribution of Nu is completely linear. The distribution of the mean Nusselt number becomes increasingly non-linear with the strengthening of the convective transport in the cases of higher values of Ra for all volume fractions of Al2O3 nanoparticles.

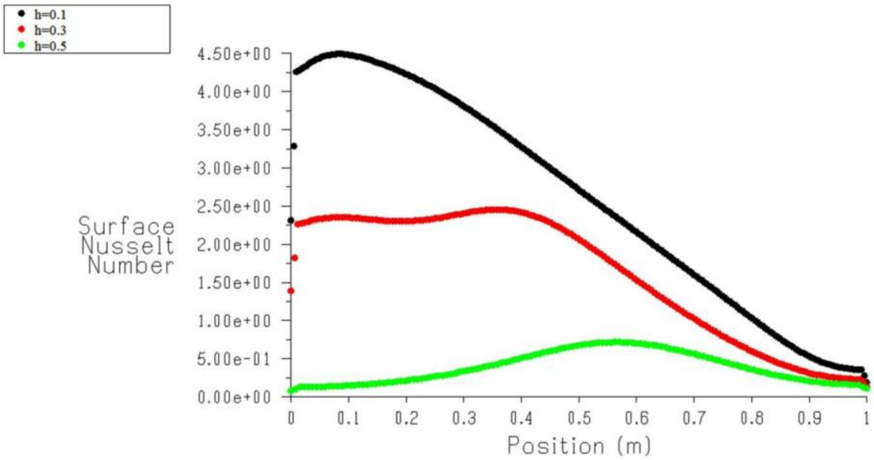


The enhancement of heat transfer is plotted with respect to the Al2O3 nanoparticles volume fraction at different Rayleigh numbers as shown in above figure (b). Considering the whole range of Rayleigh numbers, the figure illustrates that heat transfer increases in the case of an increasing solid volume fraction φ. It is interesting to observe that the heat-transfer enhancement is an increasing linear function of the volume fraction in the cases of the lower values of the Rayleigh number (Ra 104), while the higher values of the Rayleigh number (Ra ≤ 104) are characterized with a non-linear increase in the heat-transfer enhancement.

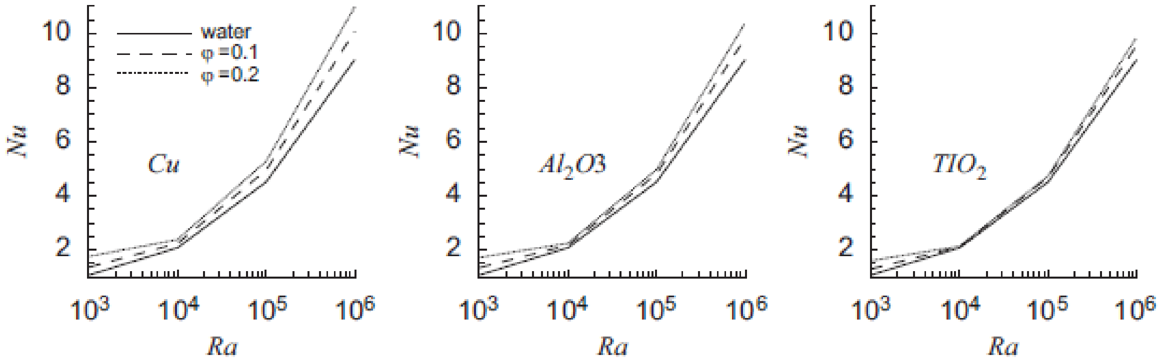
3. Finally, the enhancement of the heat transfer for φ ≤ 0.03 is similar for all the values of Ra and as the volume fraction further increases, the heat transfer is greater with the low Rayleigh numbers than with the high Rayleigh numbers. This is related to the difference between the conduction dominated mechanism for the heat transfer at a low Ra and the convection mechanism at a high Ra.



4. The above figure indicates the mid plane temperature variation with partition height. As it was concluded before, the increasing partition height leads to a decrease in the temperature gradient. At h=0.1, gradient increase is not very clear but the highest amount of the decrease is seen at h=0.5. It should be noted that the gap which occurs at h=0.5, is because of the partition's adiabatic surface.



5. This figure shows the variation of the Nusselt number on the hot wall of the cavity. It can be seen that by increasing partition height, Nusselt number along the hot wall decreases. It is because; the partition limits the fluid flow in the cavity.



6. This shows the relationship between solid particle volume fraction and heat transfer. We observe for all three nanofluids that increasing solid particle volume fraction from 0.1 to 0.2 increases heat transfer. About the same increase is obtained if we compare pure water and nanofluid. The increase in heat transfer is highest when using Cu nanofluid and lowest when using TiO2 nanofluid.

CONCLUSIONS

In the present study, the heat-transfer characteristics of the steady laminar natural-convection water-based Al2O3 nanofluids in a cubic enclosure with differentially heated side walls have been numerically studied. The effects of the Rayleigh number (103 ≤ Ra ≤ 105) and the solid-volume fraction (0 ≤ φ ≤ 0.20) have been systematically investigated. The influence of computational grid refinement on the present numerical predictions was studied throughout the examination of the grid convergence for the natural convection at Ra = 105. By utilizing extremely fine meshes, the resulting discretization error for Nu is well below 0.01 %. The numerical method was validated for the case of the convection of air (Pr = 0.71) in a cubic cavity, and its results are available in the open literature. A remarkable agreement of our results with the benchmark results of de Vahl Davis yields sufficient confidence in the present numerical procedure and its results. The highly accurate numerical results confirmed some important points, such as:

- Both the increasing value of the Rayleigh number and the solid-volume fraction of the nanoparticles augment the heat-transfer rate (the mean Nusselt number).

- The mean Nusselt number Nu is an increasing function of both, the Rayleigh number Ra and the volume fraction φ of the Al2O3 nanoparticles.

- The effect of the highly conductive nanoparticles on the heat-transfer enhancement is more significant at the low values of the Rayleigh number (the conduction- dominated heat transfer).

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