e-ISSN:2582-7219

INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH IN SCIENCE, ENGINEERING AND TECHNOLOGY

Volume 7, Issue 11, November 2024

INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 7.521

6381 907 438 6381 907 438 ijmrset@gmail.com www.ijmrset.com

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 7.521| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

A Study on Natural Convection Nanofluid Flow and Heat Transfer inside a Square Cavity with Fixed a Circular Obstacle

N. Arunkumar, G.S S Manivardhan, P.Vinay, P.Praveen Kumar, A.Bhanuprakash,

Mr. N. Govinda Rao

Department of Mechanical Engineering, GMR Institute of Technology, Rajam, India

Assistant Professor, Department of Mechanical Engineering, GMR Institute of Technology, Rajam, India

ABSTRACT: The flow and heat transport of a diamond-water nanofluid in a square cavity are investigated in this work in relation to the shape of the nanoparticles. The researchers focused on three different shapes of diamond nanoparticles: sphere, column, and lamina. They employed a model that had a lid-driven square cavity with a fixed circular obstruction at the center. The work emphasizes how important nanoparticle form is for thermal conductivity, especially in applications like molecular labeling, biomolecular assays, and trace metal detection.

The examination consisted of streamline measurements, isothermal contour patterns, velocity and temperature distributions, kinetic energy, and the Nusselt number. Governing equations were solved using a finite element method (FEM). The results reveal that, relative to the sphere- and column-shaped nanoparticles, lamina-shaped nanoparticles have a better performance in terms of heat transfer and temperature distribution.

There were more circulations in the flow due to the increase in the volume fraction (Φ) of nanoparticles, and the upper side of the circulation heated up more. The size of circulation was larger with the Lamina-shaped nanoparticle than with the column and sphere-shaped nanoparticles. Interestingly, in the presence of Lamina-shaped nanoparticles, the isothermal lines moved more quickly towards the top of the cavity. While the heat transfer rate exhibited an opposite pattern, increasing with a higher volume fraction, kinType equation here.etic energy decreased as the volume fraction of nanoparticles (Φ) increased. The study also found that Lamina-shaped nanoparticles had the maximum velocity and heat transfer rate.

I. INTRODUCTION

The impact of nanoparticle morphologies on the flow and thermal properties of nanofluids is examined in "Nanoparticles impacts on natural convection nanofluid flow and heat transfer inside a square cavity with fixed a circular obstacle." Diamond-water nanofluids with three different nanoparticle shapes—sphere, column, and lamina—in a square cavity with a heated circular barrier are the subject of this investigation. While the bottom wall and circular cavity are heated while the other walls are kept cold, the top wall is adiabatic and moves. The discussion in this paper is based on detailed analyses of streamlines, isothermal contours, distributions of velocity and temperature, kinetic energy, and the Nusselt number obtained through the finite element method (FEM) solution of coupled partial differential equations governing phenomena.

This work is motivated by the increasing application of nanofluids in industries such as solar energy, electronics cooling, biomedical devices, and nuclear reactors. The superior thermal conductivity of nanofluids, brought about by the size and shape of nanoparticles, enhances the heat transfer efficiency. During this study, the importance of particle shape for maximizing thermal performance is emphasized in confined geometries such as cavities.

The main conclusions show that lamina-shaped nanoparticles bring better performances in heat transfer and temperature distribution than column and sphere-shaped nanoparticles. Larger heat transfer rates happen due to the

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 7.521| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

increased flow mixing and thermal conduction created by the lamina form. These quantities of kinetic energy and Nusselt number really capture the same phenomenon; indeed, depending on the shape of the particles used, the difference is remarkably large.

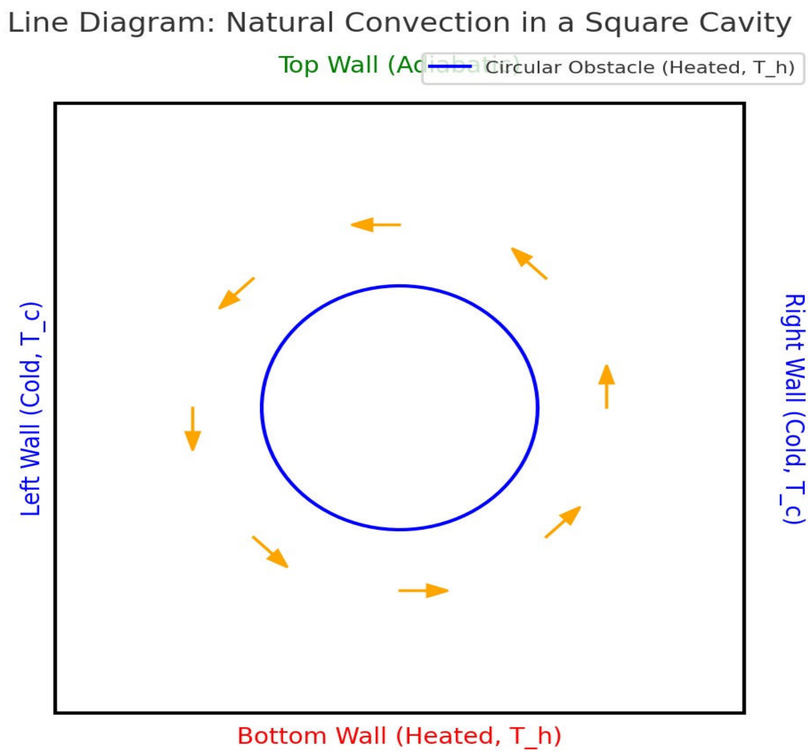

Fig . 1. Schematic model of the problem

Using parameters such as the Reynolds number (Re), Richardson number (Ri), and volume percentage of nanoparticles (ϕ), the methodology simulates the flow of nanofluids and heat transfer under various situations. Parameters are changed systematically to evaluate their effects on flow dynamics and thermal properties.

The research also provides a mesh independence analysis to ensure the reliability and numerical accuracy of the results. The results show how essential the nanoparticle shape is for engineering applications. Lamina particles are suitable for high-performance thermal systems due to their dramatically increased heat transfer efficiency. That fact, that sphere-shaped particles provide the least enhancement, proves the necessity of well-defined nanoparticle morphology selection according to particular design requirements. This paper develops the advancing field of nanofluids. The findings have relevance to the conceptual design of an efficient thermal management system in many industries, such as energy generation and electronics. To fully exploit the potential of nanofluids, the work also lays down the framework for further work on geometries, materials, and operating conditions that other researchers can pursue.

1. Problem Formulation:

Continuity equation:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$

Momentum equations:

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 7.521| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

In X-direction:

$$U\frac{\partial u}{\partial X}+V\frac{\partial u}{\partial Y}=-\frac{\partial p}{\partial x}+\frac{\mu nf}{\rho nf}\left(\frac{\partial^2 U}{\partial x^2}+\frac{\partial^2 U}{\partial y^2}\right)$$

In Y-direction:

$$U\frac{\partial V}{\partial X}+V\frac{\partial V}{\partial Y}=-\frac{\partial p}{\partial Y}+\frac{\mu nf}{\rho nf}\left(\frac{\partial^2 V}{\partial X^2}+\frac{\partial^2 V}{\partial Y^2}\right)+\frac{\beta nf}{\rho nf}g.\theta$$

Energy equation:

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

Where:

- U,V: Dimensionless velocity components in X and Y directions
- P: Dimensionless pressure
- θ: Dimensionless temperature
- ρnf: Nanofluid density
- µnf: Nanofluid dynamic viscosity
- αnf: Thermal diffusivity of the nanofluid
- βnf: Thermal expansion coefficient of the nanofluid
- g: Acceleration due to gravity

2. Non-Dimensional Parameters :

Dimensionless forms of the variables and parameters are introduced:

$X=\frac{x}{L}$; $Y=\frac{y}{L}$; $\theta=\frac{T-Tc}{Th-Tc}$; $U=\frac{u}{U0}$; $V=\frac{v}{U0}$

II. METHODOLOGY

In a square cavity with a fixed circular obstruction at its center and a diamond-water nanofluid inside, the study investigates natural convection and heat transmission. The Navier-Stokes and energy equations in two dimensions, which use the Boussinesq approximation to account for buoyancy effects, are the governing equations. Stream function, velocity, and temperature are used to represent these equations, and scaling parameters for length, velocity, and temperature are used to transform them into dimensionless form .The volume fraction (Φ) and shape of the nanoparticles (sphere, column, or lamina) determine the thermophysical characteristics of the nanofluid . An adiabatic top wall, chilly vertical walls, and a heated bottom wall and circular obstruction are examples of boundary conditions .To describe the flow and thermal behavior , dimensionless parameters such as the Reynolds number (Rey), Richardson number (Ri), and Prandtl number (Pr) are included. FEM is used to develop and numerically solve a weak formulation of the governing equations. The cavity domain is divided into discrete parts, and basis functions are used to estimate the dependent variables (temperature, pressure, and velocity). By verifying element sizes and degrees of freedom (DOFs) for precise and stable solutions, the numerical implementation guarantees grid independence. To evaluate their impacts on flow and heat transfer, the research changes the Reynolds numbers (Re), Richardson numbers (Ri), and nanoparticle volume fractions (Φ). For several scenarios, kinetic energy, temperature distributions, velocity profiles, streamlines, and isothermal contours are calculated. Kinetic energy and Nusselt number are compared for various grid resolutions to ensure grid independence. It is observed that lamina-shaped nanoparticles exhibit good performance in heat transfer better than spherical and columnar geometries due to improved thermal conductivity. A variety of Ri, Re, and Φ are used within the numerical simulations. Outcomes are analyzed based on temperature fields, velocity distributions, streamlines, and isothermal contours.

The impact of nanoparticle form on flow behavior and heat transfer is specifically examined. Kinetic energy, Nusselt number, and heat transfer rates are important performance indicators. To assess their efficacy, these metrics are calculated for various nanoparticle shapes and flow conditions. In particular, the influence of geometry on natural convection patterns and thermal boundary layer formation is investigated.

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 7.521| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

III. RESULTS AND ANALYSIS

According to the study, heat transfer and fluid flow patterns are greatly influenced by the form of nanoparticles. Lamina-shaped nanoparticles exhibit the best thermal conductivity among the three investigated shapes (sphere, column, and lamina), which improves heat transmission. On the other hand, sphere-shaped nanoparticles transport heat less effectively because of their poorer thermal conductivity.

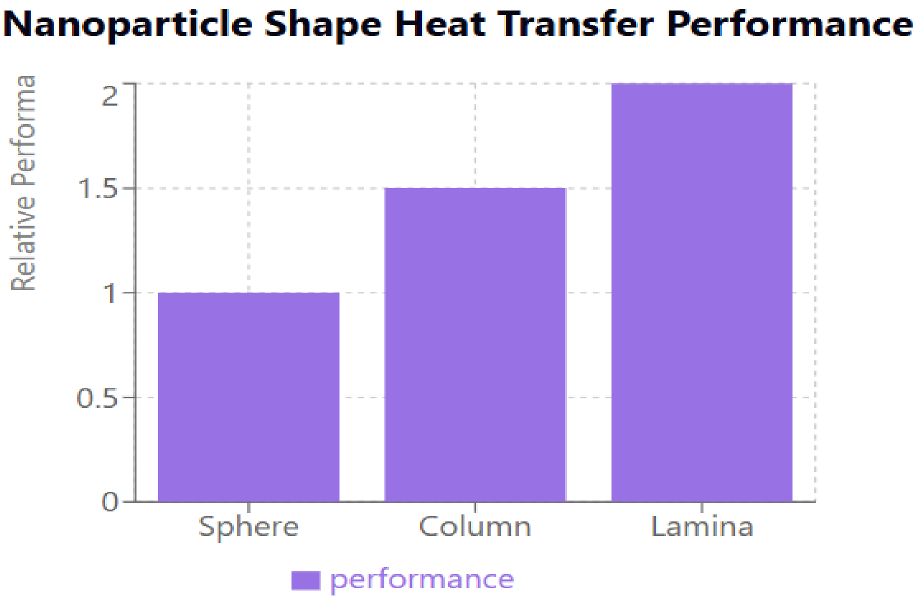

Fig . 2 . Performance of the HeatTransfer

For every form, the streamlines and isothermal contours show different flow patterns, with Lamina particles encouraging greater convection currents. When deciding whether natural or forced convection is more prevalent, the relationship between the Reynolds (Re) and Richardson (Ri) values is crucial. The buoyancy effects dominate when the Ri value becomes larger than others, allowing natural convection to dominate as a primary process. The farther the Re values increase, then the greater is the process of forced convection, which completely alters the nature of the streamlines and velocity distribution. Based on the research, Lamina nanoparticles provide the largest gain in transfer across the range of Ri and Re values in case of flows in the buoyancy-driven regime. For all geometries, the Nusselt number—a measure of the efficiency of heat transfer—is higher for higher volume fractions (Φ) of nanoparticles, with Lamina showing the greatest enhancement. A smaller barrier layer width is also obtained for higher Φ, which means there is a quicker transfer of heat. The study also emphasizes how adding diamond nanoparticles improves thermal uniformity and energy efficiency by lowering the temperature difference across the enclosure.

REFERENCES

1. Alsabery, A., Chamkha, A., Saleh, H., & Hashim, I. (2016). Heatline visualization of conjugate natural convection in a square cavity filled with nanofluid with sinusoidal temperature variations on both horizontal walls. *International Journal of Heat and Mass Transfer*, *100*, 835–850. https://doi.org/10.1016/j.ijheatmasstransfer.2016.05.031
2. Basak, T., & Chamkha, A. J. (2012). Heatline analysis on natural convection for nanofluids confined within square cavities with various thermal boundary conditions. *International Journal of Heat and Mass Transfer*, *55*(21–22), 5526–5543. https://doi.org/10.1016/j.ijheatmasstransfer.2012.05.025
3. Garbadeen, I., Sharifpur, M., Slabber, J., & Meyer, J. (2017). Experimental study on natural convection of MWCNT-water nanofluids in a square enclosure. *International Communications in Heat and Mass Transfer*, *88*, 1–8. https://doi.org/10.1016/j.icheatmasstransfer.2017.07.019

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 7.521| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

4. Garoosi, F., Jahanshaloo, L., Rashidi, M. M., Badakhsh, A., & Ali, M. E. (2015). Numerical simulation of natural convection of the nanofluid in heat exchangers using a Buongiorno model. *Applied Mathematics and Computation*, *254*, 183–203. https://doi.org/10.1016/j.amc.2014.12.116
5. Hussam, W. K., Khanafer, K., Salem, H. J., & Sheard, G. J. (2019). Natural convection heat transfer utilizing nanofluid in a cavity with a periodic side-wall temperature in the presence of a magnetic field. *International Communications in Heat and Mass Transfer*, *104*, 127–135. https://doi.org/10.1016/j.icheatmasstransfer.2019.02.018
6. Khalili, E., Saboonchi, A., & Saghafian, M. (2016). Experimental study of nanoparticles distribution in natural convection of Al2O3-water nanofluid in a square cavity. *International Journal of Thermal Sciences*, *112*, 82–91. https://doi.org/10.1016/j.ijthermalsci.2016.09.031
7. Oztop, H. F., & Abu-Nada, E. (2008). Numerical study of natural convection in partially heated rectangular enclosures filled with nanofluids. *International Journal of Heat and Fluid Flow*, *29*(5), 1326–1336. https://doi.org/10.1016/j.ijheatfluidflow.2008.04.009
8. Rashid, U., Lu, D., & Iqbal, Q. (2023). Nanoparticles impacts on natural convection nanofluid flow and heat transfer inside a square cavity with fixed a circular obstacle. *Case Studies in Thermal Engineering*, *44*, 102829. https://doi.org/10.1016/j.csite.2023.102829
9. Scott, T., Ewim, D., & Eloka-Eboka, A. (2023). Experimental study on the influence of volume concentration on natural convection heat transfer with Al2O3-MWCNT/water hybrid nanofluids. *Materials Today Proceedings*. https://doi.org/10.1016/j.matpr.2023.07.290
10. Sheikhzadeh, G., Arefmanesh, A., Kheirkhah, M., & Abdollahi, R. (2010). Natural convection of Cu–water nanofluid in a cavity with partially active side walls. *European Journal of Mechanics - B/Fluids*, *30*(2), 166–176. https://doi.org/10.1016/j.euromechflu.2010.10.003
11. Sheikhzadeh, G., Dastmalchi, M., & Khorasanizadeh, H. (2013). Effects of nanoparticles transport mechanisms on Al2O3–water nanofluid natural convection in a square enclosure. *International Journal of Thermal Sciences*, *66*, 51–62. https://doi.org/10.1016/j.ijthermalsci.2012.12.001

INNO SPACE
SJIF Scientific Journal Impact Factor

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

निस्केयर NISCAIR

INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH IN SCIENCE, ENGINEERING AND TECHNOLOGY

| Mobile No: +91-6381907438 | Whatsapp: +91-6381907438 | ijmrset@gmail.com |

www.ijmrset.com