SEMARAK ILMU
PUBLISHING
202103268166(003316878-P)

Journal of Advanced Research in Fluid
Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

Numerical Investigation of Heat Transfer Enhancement of Al_2O_3 Nanofluid in Microchannel Heat Sink

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ARTICLE INFO

Article history:
Received 3 February 2023
Received in revised form 18 May 2023
Accepted 25 May 2023
Available online 14 June 2023

ABSTRACT

This study focusses on using computational fluid dynamics (CFD) to study the enhancement of heat transfer from the use of AL_2O_3 nanofluid in a microchannel heat sink (MCHS) to develop a more efficient cooling device for high-power integrated circuits. The objective is to investigate the heat transfer performance, parameters, and enhancement rate using Ansys Fluent software, and to compare the results with experiments to show the effectiveness of this method. This study will also focus on the relationship between the friction fraction and nanoparticles volume fraction to improve the heat transfer enhancement in the MCHS. The temperature, pressure, heat transfer coefficient, Nusselt number, and friction coefficient are analysed in this study. The results showed that an increase in the volume fraction of the nanofluid leads to an increase in the average heat transfer coefficient. The results showed that for 4% nanofluid volume concentration, the Nusselt Number has improved by 10% compared to pure water. However, an increase in volume concentration also resulted in an increase in pressure drop.

Keywords:
Microchannel Heat Sink (MCHS); heat enhancement; nanofluid; ANSYS FLUENT

1. Introduction

In chips that generate a significant amount of heat, air cooling is not effective enough to achieve the best temperature reduction. Therefore, the preferred method is to use liquid cooling. Microchannel heatsinks, which are small and have excellent heat transfer properties, have been extensively researched since they were initially introduced by Tuckerman and Pease [1]. One of the most effective approaches to address the challenge of high heat flux is the utilization of microchannels in heatsinks operating with a single-phase cooling method (known as MHS) [2]. One of the most efficient methods to deal with the heat dissipation issue caused by excessive heat flux is to use cooling systems that combine nanofluids with microchannel heat sinks.

Researchers have recently become more interested than ever in using nanofluids as cooling fluid. Choi used the term "nanofluid" for ordinary liquids containing nanoscale metallic and non-metallic

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https://doi.org/10.37934/arfmts.107.1.1928

particles for the first time. These liquids might be a great contender to improve heat transfer performance and shrink the size of heat transfer systems [3]. Common industrial working fluids, including water, ethylene glycol, and oil, have poorer thermal conductivity compared to metals and metal oxides. Several numerical models and tests have lately been carried out to evaluate the impact of nanofluid on increasing the rate of heat transfer in different heat-exchangers. In order to improve heat transfer using nanofluid, factors such as the base fluid type, the nanoparticle type, and the concentration are taken into account [4-6]. Nanofluids provided greater heat transfer compared to base fluids due to their higher thermal conductivity [7]. The absorption of nanofluid heat transfer in MCHS was reported to increase compared to lower flow rates [8,9]. Murshed *et al.,* [10] affirmed the significant role of nanofluids in the revolution of cooling technologies in the future of the electronics industry.

By adding Al_2O_3 nanoparticles to water with a volume fraction of 8%, Farsad *et al.,* [11] found a 4.5% increase in the heat dissipation rate for the flow of aluminium oxide water nanofluid in a copper MCHS. In a computational simulation for the laminar flow of water-based Al_2O_3 nanofluid in an MCHS, Hung *et al.,* [12] claimed that as the volume of Al_2O_3 nanoparticles increased from 1% to 5%, the heat exchange rate initially increased and then decreased. According to Seyf and Mohammadian's [13] numerical calculations, the friction factor increases as mass flow increases, but volume fraction has an effect on pumping power. In a flow of Al_2O_3-H_2O, Snoussi *et al.,* [14] observed an increase in pressure drop and heat transfer while also detecting an increase in volume fraction [15,16].

This research aims to investigate the heat transfer enhancement of the use of AL_2O_3 nanofluid in a microchannel heat sink (MCHS) for electronic devices. The objectives of the research are to study the heat transfer performance in a MCHS, investigate the heat transfer parameters and rate of enhancement using AL_2O_3 nanofluid. Ansys Fluent software is used for numerical investigation and analysis of various parameters such as Reynold's Number, fluid flow, and friction factor. The study focusses on different volume fractions of the AL_2O_3 nanofluid to determine its efficiency in enhancing heat transfer and reducing pressure drop in the MCHS. The results of this research can be applied in the design and development of future electronic devices.

2. Methodology

This research uses numerical investigation to study the enhancement of AL_2O_3 nanofluid heat transfer in a microchannel heat sink (MCHS). The methodology includes selecting parameters, defining the problem statement and objectives, importing the model to ANSYS workbench for meshing and boundary labelling, and running simulations on ANSYS Fluent with different volume fractions of AL_2O_3 to evaluate the rate of heat dissipation from the MCHS.

2.1 Mathematical Modelling

The governing equations for continuity, momentum, and energy are as follows [17-20]

Continuity equation

$$\nabla\left(\rho_{nf} v_{mix}\right) = 0 \tag{1}$$

Momentum equation

$$\nabla\left(\rho_{nf} v_{mix}\, \nabla v_{mix}\right) = -\nabla p + \nabla\left(\mu_{nf} . \nabla v_m\right) \tag{2}$$

Energy equation

$$\nabla\left(\rho . c_p . v_m . \mathrm{T}\right) = \nabla(k_{nf} . \nabla T) \tag{3}$$

This study uses nanofluid as a working fluid, modelled as a single-phase fluid, to study the flow and heat transfer enhancement in a microchannel heat sink (MCHS). The simulation is done using ANSYS Design Modeler to create the geometry of the MCHS, which is then run on ANSYS Fluent to evaluate the rate of heat dissipation and heat transfer characteristics of the nanofluid in the MCHS. The fluid domain is single-phase, laminar, and incompressible, with the inlet temperature set at 300K. The width and height of the microchannel are defined in micrometres, and the length of the microchannel is 1000 mm. The results will be used to compare them with previous research done in the same field. Figure 1 and Figure 2 show the dimensions used in millimetres to create the geometry of the microchannel heat sink.

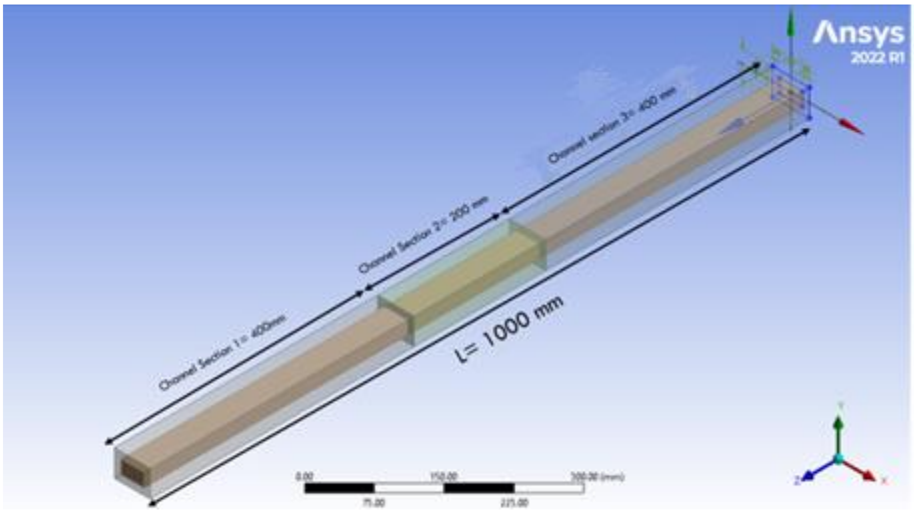

Fig. 1. The length of the microchannel heat sink

Channel section 1 is where the nanofluid enters the fluid domain. It is then flow through the heated section which is the channel section 2. Lastly, channel section 3 is where the nanofluid flows out of the fluid domain. This section is split is done to study the temperature, pressure, heat transfer coefficient, Nusselt number and friction of the fluid domain where the AL_2O_3 nanofluid with different volume fraction flows through.

2.2 Thermal Physical Properties of AL_2O_3 Nanofluid

After determining the dimension of microchannel heat sink, Table 1 below shows the nanofluid properties of different volume fractions which will be used in the fluid domain.

Table 1
Thermal Physical Properties of AL_2O_3 Nanofluid

Volume Fraction, ϕ	Density, $\boldsymbol{\rho}$ (kg/m^3)	Specific Heat, C_p (J/kgK)	Thermal conductivity, K (W/mK)	Viscosity, µ (kg/ms)
Φ = 0%	981.3	4189	0.643	0.0006
Φ = 1%	1007.4	4154.7	0.765	0.000612
Φ = 3%	1059.8	4086.2	0.798	0.000642
Φ = 5%	1112.2	4017.8	0.828	0.000672

The properties of the equivalent homogeneous fluid are estimated as follows

The density of the nanofluid is [21-23]

$$\rho_{nf} = (1 - \varphi)\rho_{bf} - \varphi\rho_{np} \tag{4}$$

The specific heat capacity of the nanofluid is defined as

$$Cp_{nf} = (1 - \varphi)Cp_{bf} - \varphi Cp_{np} \tag{5}$$

The thermal conductivity of the nanofluid is [6]

$$k_{nf} = \frac{k_{bf} + k_{np} + 2k_{bf} - 2\varphi(k_{bf} - k_{np})}{k_{np} + 2k_{bf} + \varphi(k_{bf} - k_{np})} \tag{6}$$

The effective dynamic viscosity of the nanofluid is

$$\mu_{nf} = \mu_{bf}(123\varphi^2 + 7.3\varphi + 1) \tag{7}$$

2.3 Model Validation and Governing Equations

The Reynolds number plays an important role in foreseeing patterns in fluid behaviour. In this numerical study, the Reynolds number formula is used to determine the velocity for each Reynolds number which is 100, 200, 300, 400 and 500 with different volume fractions. For the width of the fluid domain, the microchannel (Wcf) is 35mm, the height of the microchannel (Whf) is 20mm, the length L is 1000mm, and the inlet of the microchannel fluid adopts the velocity inlet boundary and the temperature of the inlet fluid is set at 300K.

The microchannel Reynolds number is

$$Re = \frac{\rho_f \, U_{in} \, D_h}{\mu_f} \tag{8}$$

where U_{in} is inlet velocity. The scale of microchannels can be defined as follows

$$D_h = \frac{2W_{hf}W_{cf}}{W_{hf} + W_{cf}} \tag{9}$$

The average temperature T_c of the heat transfer surface and the average temperature T_f of the whole microchannel fluid domain can be defined respectively as

$$T_c = \frac{\int T dA}{\int dA} \tag{10}$$

$$T_f = \frac{\int \rho_f T dV}{\int \rho_f dV} \tag{11}$$

Thus, the average heat transfer coefficient can be expressed as follows.

$$h = \frac{qA_b}{A_c(T_c - T_f)} \tag{12}$$

where A_b is the heating area of the bottom of the thermal sink and A_c is the heat exchange area between the fluid domain and the solid domain in the microchannel heat sink.

The average Nusselt number is defined as follows [24]

$$Nu = \frac{hD_h}{\lambda_f} \tag{13}$$

3. Results

The simulation in this chapter used ANSYS FLUENT to investigate the enhancement of the heat transfer of the AL_2O_3 nanofluid in a microchannel heat sink with different volume fractions. The results of the simulation included a grid independence test, temperature and pressure contours. The simulation examined three conditions: heat transfer coefficient, Nusselt number, and friction factor. The results were then compared with previous studies on this topic. In general, the simulation and analysis aimed to understand the effect of different volume fractions of AL_2O_3 nanofluid on the heat transfer performance of a microchannel heat sink.

3.1 Grid Independence Test

Grid independence test was first conducted using grid resolutions which were applied on MCHS. As illustrated in Figure 2, the outward velocity and number of elements converged when fine mesh is used. To ascertain the accuracy of the simulation results, the accuracy of the simulation results, the third finest mesh sizing (551232 number of elements) were used in this study.

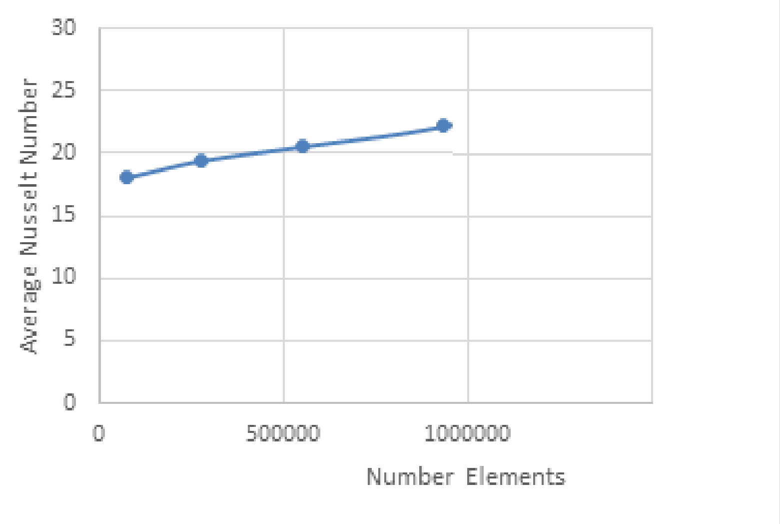

Fig. 2. Grid independence test conducted on Nusselt number

3.2 Pressure Drop

Based on the results of numerical simulations, the effect of the Reynold number and volume fraction of the AL_2O_3 nanofluid on the average pressure in the microchannel heat sink (MCHS) can be seen in Figure 3.

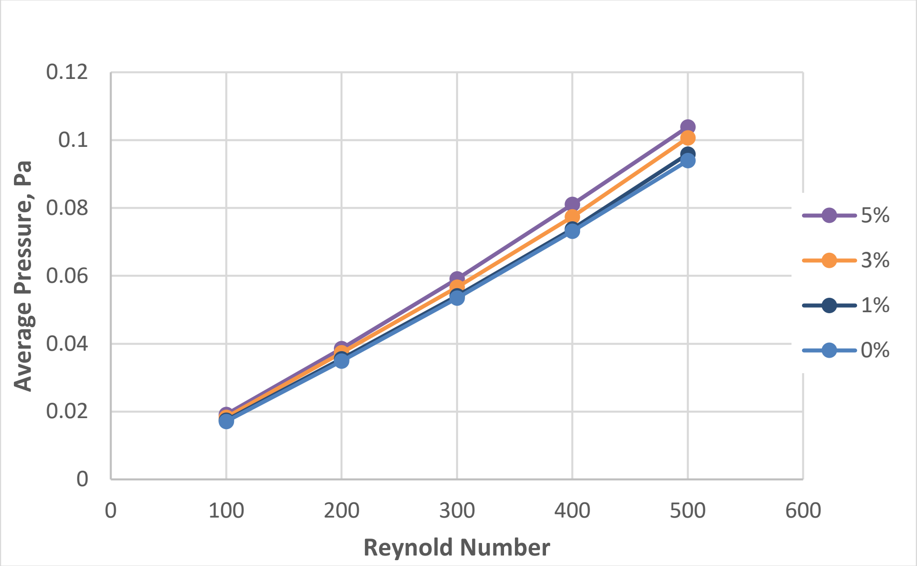

Fig. 3. Influence of nanofluid volume fraction of pressure in MCHS

This passage discusses the results of a simulation that was run to investigate the effects of Reynolds number and volume fraction of a specific type of nanofluid (AL_2O_3) on pressure within a microchannel heat sink (MCHS). The results, which are illustrated in a figure, show that as the Reynolds number increases, the pressure within the MCHS also increases. This trend is the same for both nanofluids that were tested. Furthermore, the results show that as the volume fraction of the nanofluid increases, the pressure within the MCHS also increases. This is explained by the increased viscosity of the nanofluid caused by a higher concentration of nanoparticles in the base fluid, which leads to an increase in pressure drop.

3.3 Heat Transfer Coefficient

Based on the results of the numerical simulations, the effect of Reynolds number and volume fraction of the AL_2O_3 nanofluid on the average heat transfer coefficient in MCHS can be seen in Figure 4.

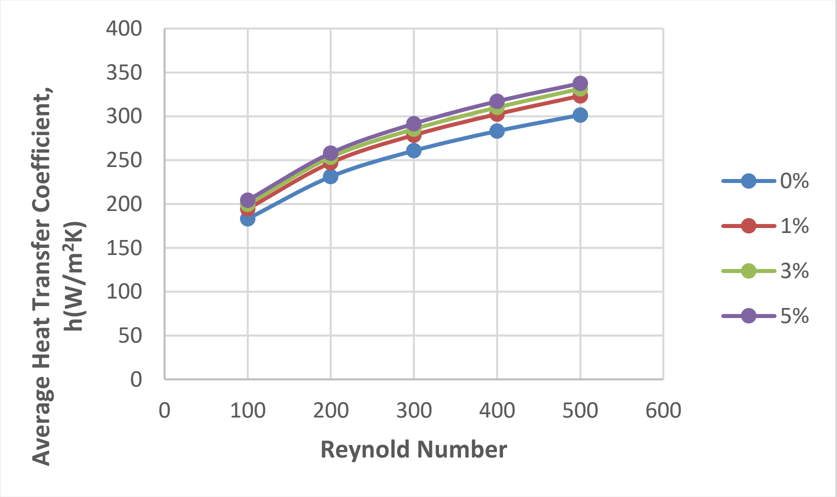

Fig. 4. The effect of nanofluid volume fraction on heat transfer coefficient

The study found that as the Reynolds number and volume fraction of nanoparticles in the base fluid increase, the average convective heat transfer coefficient also increases significantly. This is because the thermal conductivity and heat absorption capability of the coolant improves resulting in a better heat transfer coefficient. The study also observed that at low Reynolds numbers, the slope of the heat transfer coefficient is steep but at high Reynolds numbers, the slope is milder. This is due to the increasing thermal length needed for thermal development as the Reynolds number increases. Adding (5%) volume fraction raises heat transfer coefficient 12% compared to pure water.

3.4 Nusselt Number

Figure 5 shows the effects of the volume fraction of the AL_2O_3 nanofluid nanoparticles on the Nusselt number with different Reynolds numbers in the microchannel heat sink (MCHS). The results show that the average Nusselt number increases with increasing Reynolds number, and that increasing the nanoparticle volume fraction can improve the heat transfer ability of the nanofluids.

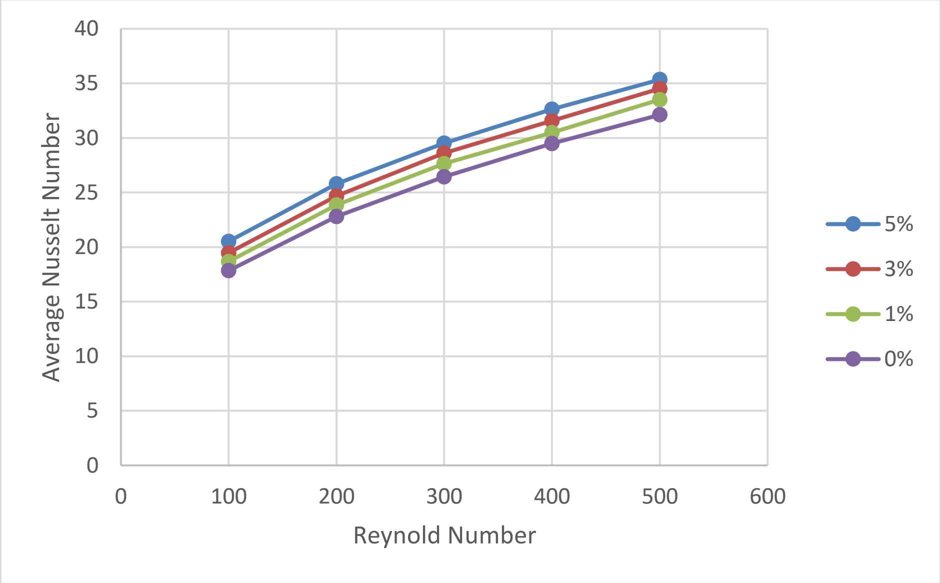

Fig. 5. Influence of nanofluid volume fraction on Nusselt Number

The Nusselt number is a dimensionless number used to measure the heat transfer performance of fluid flow in a heat exchanger. It compares the heat transfer rate in a system with the heat transfer rate that would occur if the heat were transferred only by conduction. In this case, the study is using the Nusselt number to compare the impact of different volume fractions of nanofluid on the thermal conductivity of fluid. This is used as a metric for comparison in the analysis to evaluate the effectiveness of the nanofluid in improving heat transfer in the system. It is then compared with previous study. As it can been in above figure, the effectiveness of the nanofluid increases as the Reynolds number increases.

3.5 Friction Coefficient

Based on the results of numerical simulations, the variation of Reynold number and volume fraction of AL_2O_3 nanofluid on the friction coefficient in the microchannel heat sink (MCHS) can be seen in Figure 6. The simulation results show that the friction coefficient decreases with increasing

Reynolds number. Moreover, the differences in the friction coefficients caused by different nanoparticle volume fractions decrease with the increase of the Reynolds number.

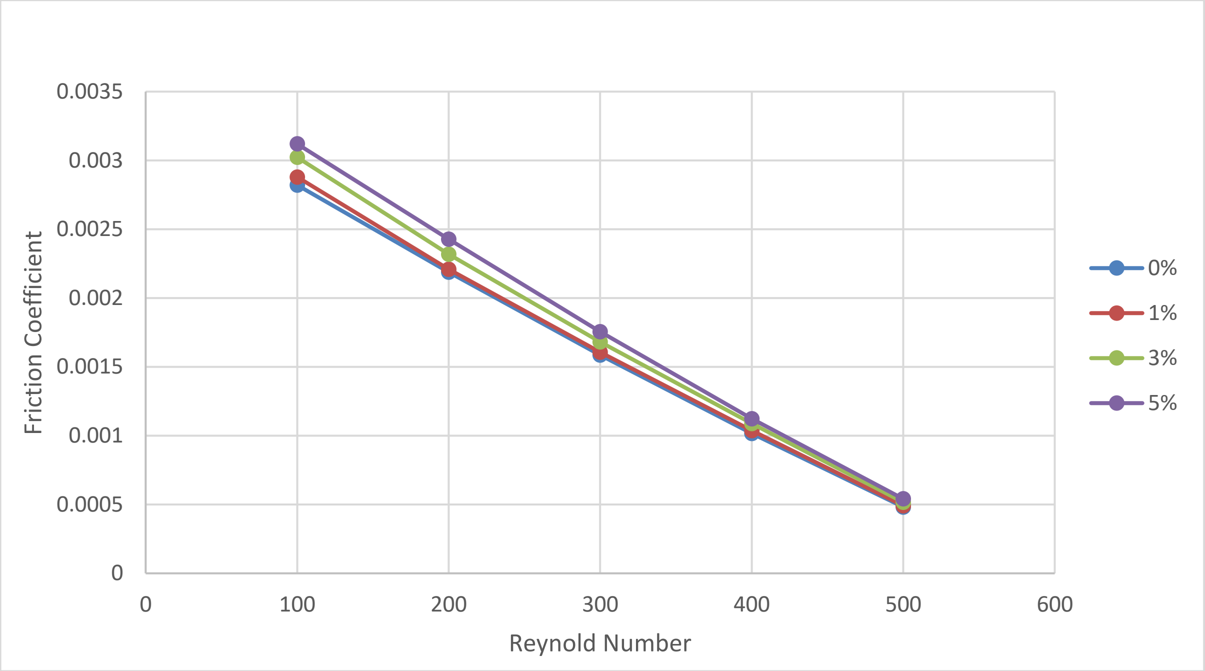

Fig. 6. Influence of nanofluid volume fraction on friction coefficient

4. Conclusions

In this research a numerical investigation of the flow and heat transfer characteristics of a microchannel heat sink is carried out using an AL_2O_3 nanofluid with different volume fractions. The study uses ANSYS FLUENT software to solve the governing equations for incompressible and laminar flow in three dimensions. The results show that as the volume concentration of the nanofluid increases, the average heat transfer coefficient and the friction coefficient also increase. Further research will be carried out for the influence of the aspect ratio of microchannels on the fluid flow and heat transfer characteristics of nanofluids in microchannels.

Acknowledgement

The corresponding author acknowledge the Research Management Centre, (RMC), Universiti Tun Hussein Onn Malaysia for the financial support under the RMC Research Fund (H768).

References

[1] Tuckerman, David B., and Roger Fabian W. Pease. "High-performance heat sinking for VLSI." *IEEE Electron device letters* 2, no. 5 (1981): 126-129. https://doi.org/10.1109/EDL.1981.25367

[2] Chu, Wen-Xiao, Yu-Wei Shen, and Chi-Chuan Wang. "Enhancement on heat transfer of a passive heat sink with closed thermosiphon loop." *Applied Thermal Engineering* 183 (2021): 116243. https://doi.org/10.1016/j.applthermaleng.2020.116243

[3] Lee, S., SU-S. Choi, S, and Li, and J. A. Eastman. "Measuring thermal conductivity of fluids containing oxide nanoparticles." (1999): 280-289. https://doi.org/10.1115/1.2825978

[4] Elfaghi, Abdulhafid MA, Alhadi A. Abosbaia, Munir FA Alkbir, and Abdoulhdi AB Omran. "Heat Transfer Enhancement in Pipe Using Al2O3/Water Nanofluid." *CFD Letters* 14, no. 9 (2022): 118-124. https://doi.org/10.37934/cfdl.14.9.118124

[5] Elfaghi, Abdulhafid MA, Alhadi A. Abosbaia, Munir FA Alkbir, and Abdoulhdi AB Omran. "CFD Simulation of Forced Convection Heat Transfer Enhancement in Pipe Using Al2O3/Water Nanofluid." *Journal of Advanced Research in Numerical Heat Transfer* 8, no. 1 (2022): 44-49. https://doi.org/10.37934/cfdl.14.9.118124

[6] Abugnah, Elhadi Kh, Wan Saiful-Islam Wan Salim, Abdulhafid M. Elfaghi, and Zamani Ngali. "Comparison of 2D and 3D modelling applied to single phase flow of nanofluid through corrugated channels." *CFD Letters* 14, no. 1 (2022): 128-139. https://doi.org/10.37934/cfdl.14.1.128139

[7] Eastman, Jeffrey A., S. U. S. Choi, Sheng Li, W. Yu, and L. J. Thompson. "Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles." *Applied physics letters* 78, no. 6 (2001): 718-720. https://doi.org/10.1063/1.1341218

[8] Chein, Reiyu, and Jason Chuang. "Experimental microchannel heat sink performance studies using nanofluids." *International journal of thermal sciences* 46, no. 1 (2007): 57-66. https://doi.org/10.1016/j.ijthermalsci.2006.03.009

[9] Ijam, Ali, Rahman Saidur, and P. Ganesan. "Cooling of minichannel heat sink using nanofluids." *International Communications in Heat and Mass Transfer* 39, no. 8 (2012): 1188-1194. https://doi.org/10.1016/j.icheatmasstransfer.2012.06.022

[10] Murshed, SM Sohel, and CA Nieto De Castro. "A critical review of traditional and emerging techniques and fluids for electronics cooling." *Renewable and Sustainable Energy Reviews* 78 (2017): 821-833. https://doi.org/10.1016/j.rser.2017.04.112

[11] Farsad, E., S. P. Abbasi, M. S. Zabihi, and J. Sabbaghzadeh. "Numerical simulation of heat transfer in a micro channel heat sinks using nanofluids." *Heat and mass transfer* 47, no. 4 (2011): 479-490. https://doi.org/10.1007/s00231-010-0735-y

[12] Hung, Tu-Chieh, Wei-Mon Yan, Xiao-Dong Wang, and Chun-Yen Chang. "Heat transfer enhancement in microchannel heat sinks using nanofluids." *International Journal of Heat and Mass Transfer* 55, no. 9-10 (2012): 2559-2570. https://doi.org/10.1016/j.ijheatmasstransfer.2012.01.004

[13] Seyf, Hamid Reza, and Shahabeddin Keshavarz Mohammadian. "Thermal and hydraulic performance of counterflow microchannel heat exchangers with and without nanofluids." (2011): 081801. https://doi.org/10.1115/1.4003553

[14] Snoussi, L., N. Ouerfelli, K. V. Sharma, N. Vrinceanu, A. J. Chamkha, and A. Guizani. "Numerical simulation of nanofluids for improved cooling efficiency in a 3D copper microchannel heat sink (MCHS)." *Physics and Chemistry of Liquids* 56, no. 3 (2018): 311-331. https://doi.org/10.1080/00319104.2017.1336237

[15] Krishna, V. Murali, M. Sandeep Kumar, R. Muthalagu, P. Senthil Kumar, and R. Mounika. "Numerical study of fluid flow and heat transfer for flow of Cu-Al2O3-water hybrid nanofluid in a microchannel heat sink." *Materials Today: Proceedings* 49 (2022): 1298-1302. https://doi.org/10.1016/j.matpr.2021.06.385

[16] Bhosale, Sushant S., and Anil R. Acharya. "Review on applications of micro channel heat exchanger." *Int. Res. J. Eng. Technol* 7, no. 04 (2020).

[17] Abobaker, Mostafa, Abdulhafid M. Elfaghi, and Sogair Addeep. "Numerical Study of Wind-Tunnel Wall Effects on Lift and Drag Characteristics of NACA 0012 Airfoil." *CFD Letters* 12, no. 11 (2020): 72-82. https://doi.org/10.37934/cfdl.12.11.7282

[18] Elfaghi, A. M., W. Asrar, and A. A. Omar. "A High Order Compact-Flowfield Dependent Variation (HOC-FDV) Method for Inviscid Flows." *International Journal for Computational Methods in Engineering Science and Mechanics* 11, no. 5 (2010): 258-263. https://doi.org/10.1080/15502287.2010.501322

[19] Elfaghi, Abdulhafid M., Waqar Asrar, and Ashraf A. Omar. "Comparison of high-order accurate schemes for solving the nonlinear viscous burgers Equation." *Australian Journal of Basic and Applied Sciences* 3, no. 3 (2009): 2536-2543.

[20] Alkrbash, Abdulbaset S., Alhadi A. Abosbaia, and Abdulhafid M. Elfaghi. "Comparison of basic iterative methods used to solve of heat and fluid flow problems." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 101, no. 1 (2023): 186-191. https://doi.org/10.37934/arfmts.101.1.186191

[21] Elfaghi, Abdulhafid MA, and Muhammad Syahmi Mohammad Hisyammudden. "Computational Simulation of Heat Transfer Enhancement in Heat Exchanger Using TiO_2 Nanofluid." *Journal of Complex Flow* 3, no. 2 (2021): 1-6. https://doi.org/10.37934/cfdl.14.9.118124

[22] Elfaghi, Abdulhafid MA, and Musfirah Mustaffa. "Numerical Simulation of Forced Convection Heat Transfer in Pipe Using Different Nanoparticles." *Journal of Complex Flow* 3, no. 2 (2021): 33-37.

[23] Abobaker, Mostafa, Sogair Addeep, Lukmon O. Afolabi, and Abdulhafid M. Elfaghi. "Effect of Mesh Type on Numerical Computation of Aerodynamic Coefficients of NACA 0012 Airfoil." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 87, no. 3 (2021): 31-39. https://doi.org/10.37934/arfmts.87.3.3139

[24] Sheng, Wong Mian, Abdulhafid M. Elfaghi, and Lukmon Owolabi Afolabi. "Numerical Study on Heat Propagation in Laptop Cooling System." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 99, no. 1 (2022): 58-65. https://doi.org/10.37934/arfmts.99.1.5865