Computational fluid dynamics heat transfer analysis of double pipe heat exchanger using nanofluid MnFe$_2$O$_4$ with ethylene glycol/water

Avita Ayu Permanasari$^{1,2}$*, Muhammad Hilmi Rusli$^1$, Poppy Puspitasari$^{1,2}$, Sukarni Sukarni$^{1,2}$, Mirza Abdillah$^3$

1 Department of Mechanical Engineering, Faculty of Engineering, State University of Malang
Semarang 5, Malang 65145, Indonesia
*Email: avita.ayu.ft@um.ac.id

2 Centre of Advanced Materials for Renewable Energy (CAMRY), State University of Malang
Semarang 5 Malang 65145, Indonesia

3 Department of Civil Engineering, Faculty of Engineering, State University of Malang
Semarang 5, Malang 65145, Indonesia

Abstract. The heat exchanger is an essential instrument in heat transfer. Various efforts have been carried out to improve heat transfer features. One of them is by adjusting the conventional cooling fluid using nanofluid. This study used MnFe$_2$O$_4$ nanoparticle along with fluid obtained from a mixture of ethylene glycol (EG) and water. This research aims to identify heat transfer characteristics of a double pipe heat exchanger with MnFe$_2$O$_4$-EG/Water nanofluid using the CFD simulation method. The EG/Water mixture variation was 20, 40, 60, and 80% with MnFe$_2$O$_4$ concentration of 0.05%. Besides, the nanofluid flow was also varied by 0.2; 0.4; and 0.6 l min$^{-1}$. The research results show that MnFe$_2$O$_4$ nanofluid effects on heat transfer characteristics encounter an increase following the rise of MnFe$_2$O$_4$ nanoparticle addition and higher water flow. In contrast, the addition of ethylene glycol carries a dreadful effect on this research. The improvement of heat transfer characteristic is hugely influenced by the increased thermal conductivity along with the addition of MnFe$_2$O$_4$ nanoparticle.

Keywords: MnFe$_2$O$_4$, nanofluid, heat exchanger, EG-Water, heat transfer characteristic, CFD.

1. Introduction

There is numerous energy transfer process, such as oil and gas, chemical industry, as well as electrical and nuclear energy. In recent decades, standard liquid, such as water, ethylene glycol, and oil, have been massively used for heat transfer systems [1]. However, the thermophysical
properties of these conventional heat transfer liquids are not sufficiently high to produce a satisfactory energy system performance. The escalation of heat conduction is critical, primarily to accelerate the heat transfer liquid performance [2]. One of the most effective means to improve thermal conductivity is the addition of solid in the scale of the nanometer into the liquid. The solid can be in the form of metal, metal oxides, graphite, or carbon nanotube. This new heat transfer liquid is named nanofluid. Nanofluid technology has gained researchers’ attention due to its excellent thermal conductivity and stability, compared to conventional heat transfer liquid or liquids with micro sized particle. In comparison to a bigger particle, nanoparticle has a more substantial surface area. The ratio of nanoparticle surface to its volume is 1000 times of microparticle [3].

A study conducted on CFD using ANSYS 14.5 with laminar flow of 1300-2200 and nanofluid with the nanoparticle volume fraction of 0.2, 0.4, and 0.6%, obtain better simulation results than the experiment data [4]. On the other hand, another study was also conducted on a shell heat exchanger with 3 tubes model simulated using CFD-fluent with Al₂O₃ nanofluid and distilled water as the basic fluid [5]. The research compares the results of CFD and experiment. The study concludes that the addition of nanoparticle into distilled water significantly accelerates the heat transfer characteristics.

There are two points to consider in the mixing process of nanoparticle and basic fluid. The thermal conductivity escalates, while the viscosity does not, due to the high viscosity, provokes high pump performance[6]. Magnetic nanoparticle, such as MnFe₂O₄, has excellent thermal conductivity. A study confirms that the thermal conductivity obtained from the addition of MnFe₂O₄ nanoparticle with a concentration of 1% is 0, 66 Wm⁻¹°C⁻¹ [7].

Computation Fluid Dynamics (CFD) research using Heat Exchanger Double Pipe that analyzes the effect of basic fluid and nanofluid flow variation toward the rate of heat transfer on the Heat Exchanger has also been carried out [8]. The total concentration of MnFe₂O₄ nanoparticle used in this research was 0.05% from the basic fluid volume and the nanofluid used was varied from 0,2 l.m⁻¹, 0,4 l.m⁻¹, to 0,6 l.m⁻¹, with ethylene glycol variation of 20, 40, 60, 80%.

2. Research methodology

2.1 Design of geometry

The design of geometry was developed using ANSYS-Fluent 18 application with 2 pipes outside and inside a long cylinder model. The pipes material was from copper, commonly, with a length of 380 mm and a diameter of 22.95 mm. The outside pipe was used to drain nanofluid, while the inside pipe was used to stream the hot fluid, as presented in Figure 1 [9]. In addition, Table 1 shows the geometry parameter of the double pipe heat exchanger.

![Geometry design of double pipe heat exchanger](image)
### Table 1. Geometry parameter of double pipe heat exchanger

| Description                                      | Size  | Unit |
|--------------------------------------------------|-------|------|
| Outside Diameter of the Outside Pipe (Do)        | 22.95 | mm   |
| Inside Diameter of Outside Pipe (Di)             | 21.45 | mm   |
| Outside Diameter of Inside Pipe (di)             | 15.45 | mm   |
| Inside Diameter of Inside Pipe (di)              | 14.45 | mm   |
| Pipe Length (l)                                  | 380   |      |

2.2 **Mesh and grid**

Meshing determines the number of influencing grid on the CFD, the smaller the element size increases the amount of mesh used in the solving process [10]. The mesh generated in this CFD found 213831 node points and 168664 elements, as illustrated in Figure 2. In this study, the number of mesh used was from the default setting in accordance with the illustrated geometry.

2.3 **Thermophysical properties of nanofluid**

Thermophysical properties refer to the physical features of nanofluid used as fluid works in the heat transfer. It includes density, specific heat, viscosity, and thermal conductivity of nanofluid. Density can be estimated by Formula 1 [13].

\[
\rho_{nf} = (1 - \varphi)\rho_{bf} + \varphi\rho_p
\]

In which, \(\rho_{nf}\) represents the nanofluid’s density (kg m\(^{-3}\)), \(\rho_{bf}\) is the basic fluid’s density (kg m\(^{-3}\)), \(\rho_p\) is nanoparticle’s density (kg m\(^{-3}\)), and \(\varphi\) means the nanoparticle’s volume fraction (%).

Additionally, the specific heat can be calculated using Formula 2.

\[
C_{Pnf} = (1 - \varphi)C_{Pm} + \varphi C_{Pp}
\]

Where \(C_{Pnf}\) represents nanofluid’s specific heat (J/kg\(^\circ\)C), \(C_{Pm}\) means the basic fluid’s specific heat (J kg\(^{-1}\)\(\circ\)C\(^{-1}\)), \(C_{Pp}\) is nanoparticle’s specific heat (J kg\(^{-1}\)\(\circ\)C\(^{-1}\)), \(\varphi\) means nanoparticle volume fraction (%). Besides, the thermal conductivity can be calculated using Formula 3.

\[
\frac{k_{nf}}{k_m} = \frac{k_p + 2k_m + 2\varphi(k_p - k_m)}{k_p + 2k_m + \varphi(k_p - k_m)}
\]
In which \( k_{nf} \) refers to nanofluid’s thermal conductivity (W m\(^{-1}\) °C\(^{-1}\)), \( k_m \) is the basic fluid’s conductivity (W m\(^{-1}\) °C\(^{-1}\)), \( k_p \) is nanoparticle’s thermal conductivity (W m\(^{-1}\) °C\(^{-1}\)), and \( \varphi \) is the nanoparticle’s volume fraction (%). Meanwhile, the viscosity can be estimated using Formula 4.

\[
\frac{\mu_{nf}}{\mu_{bf}} = 1 + 2.5\varphi
\]

In which \( \mu_{nf} \) is the nanofluid’s viscosity (kg m\(^{-1}\) s\(^{-1}\)), \( \mu_{bf} \) represents the basic fluid’s viscosity (kg m\(^{-1}\) s\(^{-1}\)), and \( \varphi \) means the nanoparticle’s volume fraction (%).

3. Results

3.1 Thermophysical properties of MnFe\(_2\)O\(_4\) nanofluid

The attainment of nanofluid’s parameter requires tests and estimations of its thermophysical properties, including density, specific heat, viscosity, and thermal conductivity. Table 2 shows the results of the calculation results of MnFe\(_2\)O\(_4\) nanofluid thermophysical properties. The results reveal an increasing thermophysical property that follows the expansion of water volume. Besides, the addition of MnFe\(_2\)O\(_4\) nanoparticle into the basic fluid also affects the growing nanofluid’s density since the components of solid is added into liquid. Therefore, nanofluid’s density also improves as the ethylene glycol concentration and nanoparticle’s fraction raise. Additionally, the ethylene glycol’s specific heat is lower than water specific heat. Consequently, the addition of MnFe\(_2\)O\(_4\) nanoparticle to the basic fluid carries a more substantial decrease in nanofluid’s specific heat. That is due to the incorporation of solid to liquid with a smaller specific heat, so that the value of nanofluid’s specific heat decreases as the amount of ethylene glycol and MnFe\(_2\)O\(_4\) nanoparticle concentration escalates.

| Types of Fluids       | Density (kg m\(^{-3}\)) | Specific Heat (J kg\(^{-1}\) °C\(^{-1}\)) | Viscosity (Pa) | Thermal Conductivity (W kg\(^{-1}\) °C\(^{-1}\)) |
|-----------------------|--------------------------|------------------------------------------|---------------|------------------------------------------|
| EG-Water (20:80)      | 1209.46                  | 3686.062                                 | 0.004194      | 0.55200                                 |
| EG-Water (40:60)      | 1226.37                  | 3352.574                                 | 0.007111      | 0.46683                                 |
| EG-Water (60:40)      | 1243.28                  | 3019.086                                 | 0.010028      | 0.39260                                 |
| EG-Water (80:20)      | 1260.19                  | 2685.598                                 | 0.012945      | 0.32940                                 |

The effects of Ethylene Glycol concentration on the thermal conductivity results show that the more level of Ethylene Glycol decreases the thermal conductivity; this is due to the lower thermal conductivity of Ethylene Glycol than the water conductivity value (Usri et al., 2015). Besides, the nanoparticles volume also enhances the thermal conductivity of nanofluid since the thermal conductivity of solid nanoparticle is higher than the liquid’s conductivity. Therefore, the nanoparticle is dissolved to the basic fluid to obtain a higher thermal conductivity. Ethylene Glycol transforms the nanofluid’s thermal conductivity to be inversely proportional to its concentration, while directly comparable to the particle addition. The effects of Ethylene Glycol show that its higher concentration raises the fluid’s viscosity value. Besides, the nanoparticle volume also upsurges the nanofluid’s viscosity; thus, the greater density of the nanofluid transforms its features to be more resilient (Azmi et al., 2015). Consequently, the nanofluid viscosity is directly proportional to the concentration of Ethylene Glycol and nanoparticle.
3.2 Heat transfer characteristics using CFD method

![Images of contour plots for right and left pipes, and contour shape of the double pipe](c)

**Figure 3.** a) Contour of the right pipe, b) Contour of the left pipe, c) Contour shape of the double pipe

| Fluid   | EG:W Concentration | Cold Water Flow | Measurements |
|---------|---------------------|-----------------|--------------|
|         |                     |                 | Fluid Temperature (Hot Water) | Fluid Temperature (Cold Water) |
| Nanofluid | 20:80               | 0.2             | Inlet °C | Outlet °C | Inlet °C | Outlet °C |
|         |                     | 0.4             |          |           |          |           |
|         |                     | 0.6             |          |           |          |           |
| Nanofluid | 40:60               | 0.2             | 60       | 57.1      | 39.9     |
|         |                     | 0.4             |          | 57        | 34.4     |
|         |                     | 0.6             |          | 56.7      | 32.5     |
| Nanofluid | 60:40               | 0.2             | 27       | 57.5      | 39.5     |
|         |                     | 0.4             |          | 57.1      | 34.05    |
|         |                     | 0.6             |          | 57        | 33.05    |
| Nanofluid | 80:20               | 0.2             | 27       | 57.9      | 39.3     |
|         |                     | 0.4             |          | 57.6      | 34       |
|         |                     | 0.6             |          | 57.2      | 32.95    |

**Table 3.** Results of temperature simulation
Figure 4. a) Reynolds Number toward flow, b) Nusselt Number toward flow

Figure 4a reveals an escalation of Reynolds number as the fluid flows. The highest Reynolds number of 361.572 is obtained by nanofluid with ethylene glycol concentration of 20% and flow of 0.6 l.m\(^{-1}\). On the other hand, the lowest Reynolds number of 36.602 is encountered by nanofluid with ethylene glycol concentration of 80% and flow of 0.2 l.m\(^{-1}\). The rise of Reynolds number is caused by the effect of the inertia and viscous force of a fluid. A fluid’s speed and density are affected by inertia force. At the same time, Figure 4 (b) identifies an upsurge on Nusselt number as the fluid flow increases. The greatest Nusselt number of 14.442 is attained by nanofluid with ethylene glycol concentration of 20% and flow of 0.6 l.m\(^{-1}\). In contrast, the lowest Nusselt amount of 8.71 is gained by nanofluid with ethylene glycol concentration of 80% with 0.2 l.m\(^{-1}\) flow. A variation of basic fluid indicates effective fluid convection heat transfer due to the increasing Reynolds number. A substantial Reynold number means a significant Nusselt number [8].

Figure 5. a) Convection coefficient toward flow, b) Total heat transfer coefficient toward flow

The convection coefficient represents the convection heat transfer on a heat exchanger. Figure 5a illustrates that the rise of the convection coefficient is hand in hand with the fluid flow.
Nanofluid with 20% ethylene glycol concentration and 0.6 l.m$^{-1}$ flow obtained the greatest convection coefficient of 515.426 W.m$^{-2}$.°C$^{-1}$. Meanwhile, the lowest conviction coefficient of 221.427 W.m$^{-2}$.°C$^{-1}$ is attained by nanofluid with ethylene glycol concentration of 80% and 0.2 l.m$^{-1}$ flow. The surge of the convection coefficient occurs as the cooling fluid flow also increases. This happens because the rate of convection coefficient is extremely affected by the Nusselt number. On the other hand, Figure 5 (b) shows an escalation of the total heat transfer coefficient following the streaming fluid flow. The biggest rate is attained by nanofluid with 20% ethylene glycol concentration and 0.6 l.m$^{-1}$ flow, 3.786 W.°C$^{-1}$. Meanwhile, the lowest rate is obtained by nanofluid with 80% ethylene glycol concentration and 0.2 l.m$^{-1}$ flow, 2.493 W.°C$^{-1}$. Those results attained since the convection and conduction coefficient escalate following the streaming flow, since the heat transfer is related to convection and conduction coefficient, so it values also increases [12].

Figures 6a demonstrates an increase of $\Delta r$LMTD following the rise of nanofluid flow. Thermal conductivity highly affects $\Delta r$LMTD escalation, a higher thermal conductivity increases the $\Delta r$LMTD value. The biggest rate of $\Delta r$LMTD (28.818°C) occurs to nanofluid with 80 % EG concentration and 0.6 l.m$^{-1}$ flow, while the lowest $\Delta r$LMTD (24.764°C) happens to nanofluid with 20 % EG concentration and 0.2 l.m$^{-1}$ flow.

Figure 7 reveals the results of the nanofluid heat transfer test. The most substantial value of the experiment (101.376 Watt) and simulation (106.881 Watt ) is presented by 20% ethylene glycol and 0.6 l.min$^{-1}$ flow. In addition, While the lowest value the experiment (65.18 Watt) and simulation (64.705 Watt) is present by 80% ethylene glycol and a 0.2 l.min$^{-1}$ flow. [8]. Besides, the rate of heat transfer using the CFD simulation method has an average error score of 4.89%, compared to experiment.
Figure 7. Comparison between simulation and experiment results of heat transfer rate of MnFe$_2$O$_4$-EG/Water Nanofluid

4. Conclusions

According to the results of MnFe$_2$O$_4$-EG/Water nanofluid CFD simulation with a variety of flow and EG concentration using a laboratory-scale double pipe heat exchanger, some conclusions are obtained. First, the higher nanofluid flow in the heat exchanger and the lower EG concentration increases nanofluid thermophysical properties and heat transfer characteristics. The best heat transfer rate of 106.881 Watt from the simulation is detected on MnFe$_2$O$_4$ – EG/Water nanofluid (20:80) with 0.6 l.m$^{-1}$ flow. The average error score of the simulation results compared to the experiment is 4.89%.

5. References

[1] M. M. Aslam Bhutta, N. Hayat, M. H. Bashir, A. R. Khan, K. N. Ahmad, and S. Khan, 2012 “CFD applications in various heat exchangers design: A review,” Appl. Therm. Eng., vol. 32, no. 1, pp. 1–12.
[2] S. Kim et al., 2018 “Comparison of CFD simulations to experiment for heat transfer characteristics with aqueous Al2O3 nanofluid in heat exchanger tube,” Int. Commun. Heat Mass Transf., vol. 95, pp. 123–131.
[3] A. A. Izadkhah, Aref A. H., Erfan-Niya H., 2014 “Cfd Simulation of Heat Transfer in Cfd Simulation of Heat Transfer in Nanofluids Containing Graphene,” no. April, pp. 0–7.
[4] P. C. Mukesh Kumar and M. Chandrasekar, 2019 “CFD analysis on heat and flow characteristics of double helically coiled tube heat exchanger handling MWCNT/water
nanofluids,” *Heliyon*, vol. 5, no. 7, p. e02030.

[5] K. Somasekhar, K. N. D. Malleswara Rao, V. Sankararao, R. Mohammed, M. Veerendra, and T. Venkateswararao, 2018 “A CFD Investigation of Heat Transfer Enhancement of Shell and Tube Heat Exchanger Using Al2o3-Water Nanofluid,” *Mater. Today Proc.*, vol. 5, no. 1, pp. 1057–1062.

[6] M. S. Kandelousi and D. D. Ganji, 2015 “Nanofluid flow and heat transfer in an enclosure,” *Hydrothermal Anal. Eng. Using Control Vol. Finite Elem. Method*, pp. 31–76.

[7] M. Amani, P. Amani, A. Kasaeian, O. Mahian, and S. Wongwises, 2017 “Thermal conductivity measurement of spinel-type ferrite MnFe2O4 nanofluids in the presence of a uniform magnetic field,” *J. Mol. Liq.*, vol. 230, pp. 121–128.

[8] D. A. Firlianda, A. A. Permanasari, P. Puspitasari, and S. Sukarni, 2019 “Heat transfer enhancement using nanofluids (MnFe2O4-ethylene glycol) in mini heat exchanger shell and tube,” *AIP Conf. Proc.*, vol. 2120.

[9] C. Abeykoon, 2020 “Compact heat exchangers – Design and optimization with CFD,” *Int. J. Heat Mass Transf.*, vol. 146, p. 118766.

[10] G. Singh and H. Kumar, 2014 “Computational Fluid Dynamics Analysis of Shell and Tube Heat Exchanger,” *J. Civ. Eng. Environ. Technol.*, vol. 1, no. 3, pp. 66–70.

[11] B. A. Bhanvase, M. R. Sarode, L. A. Putterwar, A. K.A., M. P. Deosarkar, and S. H. Sonawane, 2014 “Intensification of convective heat transfer in water/ethylene glycol based nanofluids containing TiO2 nanoparticles,” *Chem. Eng. Process. Process Intensif.*, vol. 82, pp. 123–131.

[12] A. A. Permanasari, B. S. Kuncara, P. Puspitasari, S. Sukarni, T. L. Ginta, and W. Irdianto, 2019 “Convective heat transfer characteristics of TiO2-EG nanofluid as coolant fluid in heat exchanger,” *AIP Conf. Proc.*, vol. 2120.

[13] J.P. Holman, 2009 “Heat Transfer”.