Nanofluid NiO-H₂O on heat exchanger using Taguchi optimization and numerical simulation

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Abstract. Heat exchangers that use conventional fluids such as water, ethylene glycol, and oil, which are often used in industry, have poor heat transfer characteristics. Therefore, in this study, we employed nanofluids as a substitute for conventional fluids in a heat exchanger to improve the heat transfer characteristics. This study aims to determine the potential of the working fluid in the heat exchanger system with the addition of NiO nanofluids (sintering and unsintering), which are distributed into the water base fluid. The results were then processed using a simulation on a heat exchanger to determine the heat transfer characteristics, namely the log mean temperature difference ($\Delta T_{LMTD}$) using the Taguchi and CFD methods. This study used a water flow rate (discharge) of 0.45 litre min⁻¹, 0.9 litre min⁻¹ and 1.35 litre min⁻¹, which is modeled in a simulation using variations of 1 tube, 2 tubes, and 3 tubes. Numerical simulations were carried out using the CFD method from Ansys 14.5 and the Taguchi optimization from Minitab 19. The experimental results showed that the best performance for $\Delta T_{LMTD}$ was 1.35 litre min⁻¹ using NiO-Sintering nanofluid with 1 tube.

Keywords: NiO, nanoparticles, nanofluids, sintering, unsintering, heat transfer, Taguchi, CFD

1. Introduction
Heat exchangers that use conventional fluids such as water, ethylene glycol, and oil, which are often used in industry, have less good heat transfer characteristics compared to solid materials [1]. The addition of nanoparticles in the basic fluid, which is dispersed or it’s called nanofluid, is expected to improve the heat transfer properties compared to conventional fluids [2]. The dispersed nanoparticles in the base fluid can increase density, viscosity, thermal conductivity and reduce specific heat [3]. Nanofluid has potential and useful properties for many applications in heat transfer. One of which is a heat exchanger [4].

Based on previous research, adding nanoparticles to the basic fluid using Computational Fluid Dynamics (CFD) simulations can cause a significant increase in heat transfer characteristics. One of which is the log mean temperature difference ($\Delta T_{LMTD}$) value [4]. This study used the Taguchi method, which can help determine the optimum value of the specified parameters, namely the
treatment of NiO nanoparticles (sintering and unsintering), the number of tubes, and the discharge of nanofluids in a heat exchanger [5].

2. Method and Material
The preparation of NiO nanoparticles in this study used the self-combustion method. NiO nanoparticles were made from the basic ingredients of Nickel (II) Nitrate hexahydrate powder from Sigma Aldric, then added dissolvent Ethylene Glycol in a ratio of 1: 3. Next, the sample was stirred using a magnetic stirrer for 30 minutes at a temperature of 220°C until a small explosion occurred during the heating process. Two samples of NiO nanoparticles were used in this study, where the first sample was the sintering process until a temperature of 400°C with a holding time of 1 hour. After that, the drying and crushing processes were formed, so that NiO samples were formed in powder form [6].

Figure 1. Geometry of heat exchanger. a) 1 Tube, b) 2 Tube, c) 3 Tube
The process of making these nanofluids was carried out using a two-step process method, where Nickel Oxide (NiO) nanoparticles were made in the form of dry powder, then dispersed into a fluid (distilled water) with a concentration of 0.05% in a volume of 100 ml. Nanofluids were stirred using a magnetic stirrer for 5 minutes, then sonicated using an ultrasonic sonicator for 45 minutes to minimize nanoparticle aggregation [7]. Afterward, it was awaited for a while until it reached room temperature around 27°C. The thermal conductivity of NiO/Water nanofluids was measured using the KD2 tool, and the density of nanofluids was measured using a pycnometer. The viscosity of the nanofluids was measured using an Ostwald viscometer. This nanofluid was made to determine the thermophysical properties that would be inputted to the process parameters at the processing step using CFD method.

The Taguchi method is a methodology for engineering to improve productivity during research and development so that high-quality products can be produced in a fast and low-cost manner. This study employed an orthogonal array (OA) matrix, which functioned as a determinant of the number of experiments that were carried out and could provide a lot of information based on the factors and levels that influenced it. Taguchi provided an approach through the S/N Ratio (Signal To Noise), which was used to select factors that had a contribution by reducing the resulting combination. The type used in determining the S/N ratio was based on the desired characteristics, namely larger the better, which means that if the quality of the resulting value is greater, so it would be the better [5].

| Table 1. Specification for the Size of the Heat Exchanger |
|----------------------------------------------------------|
| Information      | Size       |
| Tube Diameter   | 21.45 mm   |
| Shell Diameter  | 7.42 mm    |
| Long pipe       | 380 mm     |

This study used the CFD method with ANSYS Fluent version 14.5 software. The stages included preprocessing, processing, and postprocessing. Preprocessing is the initial step that needs to be done before performing a simulation, such as creating geometry, meshing, and defining the boundary plane of the geometry. The geometry in this study was divided into three parts, namely enclosure (boundary), tube (pipe-plate), and fluid. The geometric specifications of the heat exchanger can be seen in Table 1. After the geometry was made, the next step was the meshing stage. The mesh size contained in an object affected the accuracy of the CFD analysis to be carried out. The smaller the mesh size on an object, the more accurate the results would be. In this simulation, the smoothing quality mesh is high, as shown in Figure 2.

![Figure 2. Meshing on a heat exchanger with 2 tubes](image)

At the solution stage, there were many things that must be done in relation to determining the boundary conditions in a CFD simulation. This process is essential because almost all research parameters were processed in this stage. The stages of the solution were general, models,
materials, cell zone conditions, boundary conditions, and iterations. This simulation used the default solution method based on pressure. In this case, the fluid flow in the pipe was steady. Then, using the viscous-laminar model with k-epsilon (2 eqn), k-epsilon model in Realizable state, and Near-Wall Treatment with Enhanced Wall Treatment. In the enclosure zone, the material is air, tube zone material for aluminum, and fluid zone for sintering, non-sintering, and water without NiO nanoparticle.

3. Results and discussion

![Figure 3. Nanofluid contour simulation results on 2 tubes (NiO-sintering treatment) with discharge: a) 0.45 l min$^{-1}$, b) 0.9 l min$^{-1}$, c) 1.35 min$^{-1}$](image_url)

The results of heat exchanger simulation using the CFD method can be seen in Figure 3, which shows a contour image of heat transfer and the magnitude of the inlet and outlet temperatures. The inlet and outlet temperatures obtained from the simulation results are used to obtain the log mean temperature difference ($\Delta$TLMTD) from the heat exchanger. The result of the S/N ratio calculation, which is done in Minitab, is an analysis using the Larger the Better concept based on the level value of the factors that affect $\Delta$TLMTD. The S/N ratio calculation is selected from the largest value to determine the effect of the optimum value on $\Delta$TLMTD which can be seen in Table 2, indicating that the S/N ratio value of 29.89 is the greatest value among 27 other experiments with the best results using 1 tube (NiO- Sintering) with discharge 1.35 litre min$^{-1}$ which is 31.2286°C, as shown in Table 2. It can be seen in Table 3 that the order of the most dominant factor or the highest delta that affects $\Delta$TLMTD is the number of tubes with a delta value of 2.77, followed by discharge with a delta value of 0.93, and then NiO nanoparticle treatment with a delta value of 0.30.
Table 2. The results of the $\Delta T_{\text{LMTD}}$ Ratio Taguchi S/N trial

| No. | Treatment | Tube | Discharge (l m$^{-1}$) | $\Delta T_{\text{LMTD}}$ ($^\circ$C) | S/N Ratios ($\Delta T_{\text{LMTD}}$) |
|-----|-----------|------|------------------------|-----------------------------|----------------------------------|
| 1   | NiO-Sintering | 1    | 0.45                   | 30.5695                     | 29.7058                          |
| 2   | NiO-Sintering | 1    | 0.9                    | 31.1264                     | 29.8626                          |
| 3   | NiO-Sintering | 1    | 1.35                   | 31.1800                     | 29.8775                          |
| 4   | NiO-Sintering | 2    | 0.45                   | 22.9940                     | 27.2323                          |
| 5   | NiO-Sintering | 2    | 0.9                    | 25.1706                     | 28.0179                          |
| 6   | NiO-Sintering | 2    | 1.35                   | 26.0950                     | 28.3311                          |
| 7   | NiO-Sintering | 3    | 0.45                   | 20.8815                     | 26.3952                          |
| 8   | NiO-Sintering | 3    | 0.9                    | 23.3280                     | 27.3576                          |
| 9   | NiO-Sintering | 3    | 1.35                   | 24.2885                     | 27.7080                          |
| 10  | NiO-Sintering | 1    | 0.45                   | 30.5692                     | 29.7057                          |
| 11  | NiO-Sintering | 1    | 0.9                    | 31.1791                     | 29.8773                          |
| 12  | NiO-Sintering | 1    | 1.35                   | 31.2286                     | 29.8910                          |
| 13  | NiO-Sintering | 2    | 0.45                   | 22.9791                     | 27.2267                          |
| 14  | NiO-Sintering | 2    | 0.9                    | 25.1693                     | 28.0174                          |
| 15  | NiO-Sintering | 2    | 1.35                   | 26.1051                     | 28.3345                          |
| 16  | NiO-Sintering | 3    | 0.45                   | 20.8516                     | 26.3828                          |
| 17  | NiO-Sintering | 3    | 0.9                    | 23.3300                     | 27.3583                          |
| 18  | NiO-Sintering | 3    | 1.35                   | 24.3021                     | 27.7129                          |
| 19  | Water       | 1    | 0.45                   | 29.9477                     | 29.5273                          |
| 20  | Water       | 1    | 0.9                    | 30.7803                     | 29.7655                          |
| 21  | Water       | 1    | 1.35                   | 30.8967                     | 29.7983                          |
| 22  | Water       | 2    | 0.45                   | 21.8211                     | 26.7775                          |
| 23  | Water       | 2    | 0.9                    | 24.2490                     | 27.6939                          |
| 24  | Water       | 2    | 1.35                   | 25.3040                     | 28.0638                          |
| 25  | Water       | 3    | 0.45                   | 19.5052                     | 25.8030                          |
| 26  | Water       | 3    | 0.9                    | 22.2852                     | 26.9603                          |
| 27  | Water       | 3    | 1.35                   | 23.4073                     | 27.3870                          |

Table 3. Response value taguchi S / N ratio $\Delta T_{\text{LMTD}}$

| Level | Treatment | Tube | Debit |
|-------|-----------|------|-------|
| 1     | 28.28     | 29.78| 27.64 |
| 2     | 28.28     | 27.74| 28.32 |
| 3     | 27.98     | 27.01| 28.57 |
| Delta | 0.30      | 2.77 | 0.93  |
| Rank  | 3         | 1    | 2     |
In the next analysis, the Analysis of Variance (ANOVA) was carried out using Minitab by using the results of the trials that had been conducted 27 times. Table 4 shows that the F-value which indicates the highest weight in the optimal calculation of $\Delta T_{LMTD}$ is shown at the value of 4637.93 by the number of tubes factor, followed by discharge with an F-value of 170.75 and NiO nanoparticle treatment with an F-value of 29.11. The F-value of all parameters is more than the F table, so it can be concluded that all parameters affect $\Delta T_{LMTD}$.

| Source    | DF | Contribution | F-Value   | P-Value |
|-----------|----|--------------|-----------|---------|
| Treatment | 2  | 0.6%         | 29.11     | 0.000   |
| Tube      | 2  | 95.67%       | 4637.93   | 0.000   |
| Discharge | 2  | 3.52%        | 170.75    | 0.000   |
| Error     | 20 | 0.21%        |           |         |
| Total     | 26 | 100.00%      |           |         |

**Figure 4.** Graph of S/N Ratio at $\Delta T_{LMTD}$

**Figure 5.** Percentage of Contribution to Factors in $\Delta T_{LMTD}$
The results of the P-value show the probability distribution of certain factors with the least contribution in the calculation of $\Delta T_{\text{LMTD}}$, for all factors that have the same value, namely 0.000 where ($P < 0.05$), it can be concluded that all these parameter factors have a significant effect on $\Delta T_{\text{LMTD}}$. The percentage contribution shows the influence of the control variable in the optimal calculation of $\Delta T_{\text{LMTD}}$ among all control variables and the contribution factor can be seen in Figure 5, where the largest percentage with a value of 95.67% by the number of tubes, followed by a value of 3.52% by discharge, and then the value of 0.6% by NiO nanoparticle treatment difference [9].

4. Conclusion

Based on our research on NiO nanofluids (Sintering and Unsintering) - Water in a heat exchanger simulation using Taguchi optimization, it can be concluded that:

- The addition of NiO nanoparticles by sintering treatment can help improve heat transfer characteristics.
- The fewer number of pipes in the heat exchanger will provide an increase in the overall heat transfer and $\Delta T_{\text{LMTD}}$, while the more the number of pipes at the heat transfer rate will increase.
- The effect of adding NiO nanoparticles in Water ($H_2O$) on the heat transfer characteristics namely $\Delta T_{\text{LMTD}}$ using the Taguchi method will show the optimum value at $\Delta T_{\text{LMTD}}$ using NiO Sintering, 1 tube and discharge of 1.35 l min$^{-1}$ with a value of 31.22 °C.

5. References

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