This study investigated an aluminium oxide nanofluid water-based tube heat exchanger fitted with a corrugated copper tube under laminar flow conditions. This study is carried out to observe the heat transfer rate within the heat exchanger. The effect of nanoparticle concentrations, the flow rate of the working fluid, and the corrugated tube pitch on the heat exchanger efficiency were analysed. The results show that when Al₂O₃ water nanofluids are sandwiched between corrugated copper tubes, the heat transfer rate is significantly enhanced compared to the smooth tubes. Nanofluids of aluminium oxide were prepared with concentrations of 0.25, 0.5%, and 1% in deionised water. Corrugated tubes with 25 mm, 20 mm, and 18 mm pitches were fabricated for this investigation. The deionised water and aluminium oxide nanofluid flow rates were maintained at 0.1 m³/h, 0.15 m³/h and 0.2 m³/h, respectively. Results showed that aluminium oxide nanofluids improved the heat transfer rate related to water-based fluids. The highest heat transfer occurred in the 18-mm pitch corrugated copper tube in which 1% nanofluid volume concentration was used as the heat transfer medium. It is observed that the heat exchanger containing corrugated copper tubes with pitch 17.88 mm having 0.98 vol. % of Al₂O₃ nanofluids, flowing at 0.198 m³/h, enhances the heat transfer rate between the working fluids.

Keywords: corrugated tube, pitch, flow rate, aluminium oxide, nanofluid, heat transfer rate

1. Introduction

The constant demand for energy saving for domestic applications and industries has made heat transfer augmentation an absolute necessity. Over the past few years, research on improving heat transfer through heat exchangers has risen exponentially. In addition to reducing energy use, this heat transfer enhancement is motivated by a desire to reduce costs. Most of the studies were carried out on heat transfer optimisation to increase the efficiency of heat exchangers [1,2]. In a typical heat
exchanger, the contact area between the hot and cold fluids is a factor that determines the rate of heat transfer. [3-4].

Fluid properties like the fluid viscosity, coefficient of specific heat, and thermal conductivities can positively or negatively influence the heat transfer coefficient. Including nanoparticles in a base fluid like water can alter thermophysical and transport properties [5]. Numerous experiments confirmed that nanofluids increase heat transfer coefficients in heat exchangers [6]. Nanofluids containing metal oxide nanoparticles were found to have increased thermal conductivity effectiveness of the resulting fluid mixture. Research work by Das et al. [7] used Al$_2$O$_3$ and CuO nanofluids dissolved in water to augment the heat transfer in typical heat exchangers. They inferred that the thermal conductivity of nanofluid is typically more significant than the conventional heat transfer fluid. They also developed a model considering the fluid properties. A study showed that nanoparticles’ Brownian motion induced local convection, which increased thermal conductivity [8].

The material used as nanoparticles plays a significant role in heat transfer. Post-processing techniques like milling and sonication control the base fluid’s particle size and distribution. It was noted that particle size decreased by 36 % and 40 %, respectively, while using alumina and copper oxide subjected to ball milling. The resulting sonication process improved the centrifugal dispersion by 15 % [9]. It was found that when using titanium oxide as a working fluid at an inclination angle of 45° and an operating temperature of 80 °C, the highest heat transfer was 298 W, the most increased heat flux was 2.8 kW/m$^2$; the highest heat transfer coefficient was 1.5 W/m$^2$ °C and the highest thermal efficiency was 17 % respectively [10].

Al$_2$O$_3$ water nanofluids were examined numerically for their heat transmission and pressure drop properties in a flat coiled conical tube. The pressure drop in the nanofluid and the heat transfer were studied along with the coil pitch, cone angle, aspect ratio, and solid volume fraction. The study revealed that increasing the nanofluid’s Reynolds number, aspect ratio, and substantial volume percentage enhances the pressure drop and the heat transfer coefficient. However, increasing the conical coil tube’s cone angle and coil pitch has an opposing effect [11]. A nanofluid was synthesised by combining Al$_2$O$_3$ nanoparticles of size 43 nm and water using a microwave-assisted chemical precipitation technique. The nanofluid experiment showed that the thermal conductivity of Al2O3-water nanofluid increased by 8 % compared with the base fluid rising linearly with the nanoparticle concentration [12]. Heat transfer improvement with the Al$_2$O$_3$ water nanofluid was studied in a circular tube twin pipe heat exchanger with constant wall temperature. 0.2–2.5 vol. % nanoparticle concentrations were used in the experiment. The results showed that Brownian motion, appropriate dispersion, and migration of nanoparticles increase the thermal conductivity by 7 % and heat transfer rate by 11%, respectively [13].

Several literature works discussed optimising fluid properties, flow characteristics and design of heat transfer systems to increase the heat transfer in typical heat exchangers [14,15,16]. Numerical investigations are also carried out in heat exchangers to study the characteristics of nanofluids containing metal oxides like titanium oxide and copper oxide [17, 18]. Techniques like Multi-Layer Perceptron (MLP) neural network optimised by the Imperialist Competition Algorithm (ICA), Genetic Algorithm (GA), Neuro-Fuzzy Inference System (ANFIS), Artificial Neural Network (ANN) and Particle Swarm Optimization (PSO) were employed to obtain reliable results in unison with the experimental work [19, 20].
The optimisation function measures the solution's efficacy that can be maximised or minimised, respectively. A variant of the Teaching-Learning-Based Optimization (TLBO) algorithm was developed and used to simultaneously optimise heat exchangers for multiple criteria. Optimisation in plate fins and the shell-and-tube heat exchangers was also carried out. The effectiveness of the heat exchanger is maximised by 0.23, and the cost of the exchanger is minimised as the objective of optimisation [21]. Plate-fin heat exchangers were optimised using the Multi-Objective Improved Teaching-Learning-Based Optimization (MO-ITLBO) algorithm [22].

The present study researches nanofluids produced through hydrodynamic cavitation using ultrasonically manufactured Al₂O₃ nanoparticles. The nanofluid is thus used in the heat exchanger that contains a spiral corrugated-shaped tube. This research presents findings from examining Al₂O₃ nanofluid's convective heat transfer capability in a corrugated tube heat exchanger. The study's novelty is that the nanoparticles' volume concentration is maintained relatively large, i.e., up to 1 vol. %. This facilitates enhanced heat transfer because of the increased viscosity of the working fluid, even at elevated temperatures. The study will observe the heat transfer rate in the tube heat exchanger with a corrugated copper tube using water-based aluminium oxide nanofluid under laminar flow conditions. Water-based aluminium oxide nanofluid was prepared with varying volume concentrations, i.e., 0.25%, 0.5%, and 1%. The corrugated tube with three different pitches, i.e., 25 mm, 20 mm, and 18 mm, is fabricated for this investigation. The experimental study was conducted at three flow rates: 0.1 m³/h, 0.15 m³/h, and 0.2 m³/h with deionised water and aluminium oxide nanofluid.

2. Materials and methods

Table 1 Corrugated tubes’ specifications

<table>
<thead>
<tr>
<th>Tube Materials</th>
<th>Notation</th>
<th>Inner Diameter (mm)</th>
<th>Outer Diameter (mm)</th>
<th>Thickness (mm)</th>
<th>Pitch (mm)</th>
<th>Depth (mm)</th>
<th>Length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless Steel Tube</td>
<td>SST</td>
<td>25.4</td>
<td>26</td>
<td>02</td>
<td>-</td>
<td>-</td>
<td>1000</td>
</tr>
<tr>
<td>Copper Tube</td>
<td>CuT</td>
<td>25.4</td>
<td>26</td>
<td>02</td>
<td>-</td>
<td>-</td>
<td>1000</td>
</tr>
<tr>
<td>Corrugated Copper Tube 1</td>
<td>CuCT1</td>
<td>25.4</td>
<td>26</td>
<td>02</td>
<td>25</td>
<td>04</td>
<td>1000</td>
</tr>
<tr>
<td>Corrugated Copper Tube 2</td>
<td>CuCT2</td>
<td>25.4</td>
<td>26</td>
<td>02</td>
<td>20</td>
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<tr>
<td>Corrugated Copper Tube 3</td>
<td>CuCT3</td>
<td>25.4</td>
<td>26</td>
<td>02</td>
<td>18</td>
<td>04</td>
<td>1000</td>
</tr>
</tbody>
</table>

Figure 1 Fabricated Copper Corrugated Tubes
A straight, plain tube made using copper and hexagonally corrugated tubes of 1000 mm length, 25.4mm inner diameter, and 26mm outer diameter are used as the test segment. The geometric specifications of the tubes are given in tab 1. A copper corrugated tube with a thickness of 2mm, a depth of 4mm, and grooves with a pitch of 18, 20, and 25 mm have been fabricated for this investigation, as shown in fig 1. Fig 2 reveals the SEM images revealing the Al₂O₃ nanostructures' size and morphology. The surface is covered by an oxidation layer, indicating the location of the nano partulates. The interlocking, spherical structures show the symmetricity of the oxidation layer. Also, the thermo-physical properties of deionised (DI) water and nanoparticles are tabulated in tab 2.

<table>
<thead>
<tr>
<th>Physical properties</th>
<th>Unit</th>
<th>DI water</th>
<th>Al₂O₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>kg/m³</td>
<td>997.3</td>
<td>3970</td>
</tr>
<tr>
<td>Specific heat capacity</td>
<td>J/kg K</td>
<td>4179</td>
<td>765</td>
</tr>
<tr>
<td>Latent heat capacity</td>
<td>kJ/kg</td>
<td>2256</td>
<td>1360</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>W/mK</td>
<td>0.605</td>
<td>40</td>
</tr>
</tbody>
</table>

3. Experimental details

The experimental setup for this study includes the settling chamber, the testing section, the riser, the cooling unit, the pump, and the fluid reservoir, as shown in fig 3. The settling room helps to smooth out the fluid flow and decrease the impact at the entrance. The test section is 1000 mm long, 26 mm outer diameter, 25.4mm inner diameter, and 2mm thick. A Ni-chrome heating wire with a resistance of 100 Ω is wound around ceramic beads to produce uniform heat across the test section. Thick glass wool insulation is placed over the electrical winding to minimise the heat lost to the atmosphere. A vertical pipe serves as the riser to ensure a consistent working fluid flow throughout the testing section. Fluid is pumped through the riser and the cooling unit through which the air is
cooled. A 4-litre stainless steel tank with a drain valve serves as the reservoir for the working fluid. An autotransformer maintains a consistent heat flux in the test section [24].

![Experimentation Setup](image)

**Figure 3 Layout of Experimentation Setup**

**4. Results and discussion**

Heat transfer is experimentally examined using an Al₂O₃ water nanofluid flowing in corrugated copper tubes under various operational conditions. The nanofluid's heat transfer rate is given by the expression shown in eqn. (1) [25].

\[ Q = m \ C_p\text{nf} (T_{out} - T_{in}) \]  

(1)

Where \( m \) is the nanofluid mass flow rate, \( C_p\text{nf} \) is the adequate specific heat of the nanofluid, and \( T_{in} \) and \( T_{out} \) are the inlet and outlet temperatures of the nanofluid.

The expression shown in eqn gives the nanofluid's effective density. (2),

\[ (\rho C_p)_{nf} = (\rho C_p) (1-\phi) + (\rho C_p) \phi \]  

(2)

Where \( \rho_{nf} \) the density of the nanofluid, \( \rho_i \) is the density of the fluid (i.e., deionised water), \( \rho_s \) is the density of the nanoparticles, \( C_p_i \) is the density of the specific heat (i.e., deionised water), \( C_p_s \) is the density of the particular warmth of the nanoparticles, \( \phi \) is the volume concentration of the nanoparticle Xuan & Roetzel [22].

**4.1. Heat transfer rate at the flow rate of 0.1 m³/h**

When using a fluid flow rate at 0.1m³/h with nanofluid volume concentrations of 0.25 %, 0.5% and 1%, a copper corrugated tube with an 18mm pitch achieves the maximum heat transfer rate, as
shown in fig 4. The heat transfer rate rose by 22.93 %, 22.82 % and 26.27 % compared to a typical stainless steel tube. When the working fluid flows through the corrugate tube of pitch 18 mm, the overall heat transfer rate increases by 16 %, 17.82 % and 20.58 % more than the base copper tube [26]. Specifically, the increased thermal conductivity of the nanofluids is because of the increase in the Brownian motion of Al₂O₃ nanoparticles at elevated temperatures. Additionally, a more significant number of Al₂O₃ nanoparticles in the nanofluid shows a more substantial influence on the heat conduction in the nanofluid. This phenomenon causes the thermal conductivity ratio to increase proportionally with an increase in the loading of Al₂O₃ nanoparticles in the nanofluid. Compared with base deionised water, the overall heat transfer coefficient increases by 22.84%, 29% and 32.87%, respectively. This condition is observed when the pitches of the copper corrugated tube were 25 mm, 20 mm, and 18 mm, respectively, at the nanofluid volume concentration of 1 %, as shown in fig 5. Similarly, the heat transfer rate rises as the Al₂O₃ concentration increases but reduces with the pitch on the corrugated tube.

![Figure 4 Heat Transfer performance at the flow rate of 0.1 m³/h](image)

![Figure 5 Improvement of heat transfer rate with Al₂O₃ at the flow rate of 0.1 m³/h](image)

4.2. Heat transfer rate at the flow rate of 0.15 m³/h

The corrugated copper tube with an 18mm pitch had the highest heat transfer rate when used with a fluid flow rate of 0.15 m³/h and nanofluid volume concentrations of 0.25 %, 0.5 %, and 1 %, as shown in fig 6. Increases in heat transfer efficiency of 24.67 %, 26.67 % and 30.74 % are achieved relative to stainless steel smooth tubes. The total heat transfer rate increases by 16.31 %, 17.08 %, and 20.04 % when utilising a nanofluid concentration instead of a standard copper tube. A high heat transfer coefficient was noted for increased vol.% of Al₂O₃ nanoparticles. This is because their dispersion considerably affects thermal conductivity and modifies the flow rate and tube pitches accountable for improved heat transfer coefficient. The heat transfer coefficient surges by 28.95 %, 34.84 %, and 42.11 % at its maximum when compared to base deionised water, as shown in fig 7. This was observed in the copper corrugated tubes having varying pitches at a nanofluid volumetric concentration of 1%. Similarly, the heat transfer rate increases with an increase in the Al₂O₃ concentration. However, it slowed down when there was an increase in the pitch of the corrugated
tube. Al₂O₃ nanoparticles improve fluid flow, leading to a high shear rate at the wall and a more significant heat transfer coefficient because of the shear thinning phenomenon in nanofluids. The heat transfer coefficient increased because of Al₂O₃ nanoparticles, which can be attributed to an early shift from laminar to turbulent flow.

**Figure 6** Heat Transfer performance at the flow rate of 0.15 m³/h

**Figure 7** Enhancement of heat transfer because of Al₂O₃ at the flow rate of 0.15 m³/h

### 4.3. Heat transfer rate at the flow rate of 0.2 m³/h

**Figure 8** Heat Transfer performance at the flow rate of 0.2 m³/h

**Figure 9** Improvement of Heat transfer rate with Al₂O₃ at the flow rate of 0.2 m³/h

The maximum heat transfer rate was achieved by a corrugated copper tube with an 18mm pitch when it was used in conjunction with a fluid flow rate of 0.20 m³/h and a nanofluid volume concentration of 0.25 %, 0.5 %, and 1 %, respectively. When the nanofluid concentration was varied in the corrugated copper tube (18 mm pitch), the overall heat transfer rate increased by 17.08 %, 17.99 %, and 20.00 %, respectively. Compared to stainless steel smooth tubes, these tubes achieve increases
in heat transfer efficiency of 23.77 %, 24.58 %, and 26.76 %, respectively, as shown in fig 8. Fig 9 shows that the overall heat transfer coefficient raised by 29.38 %, 34.69 %, and 40.29 % at its highest when studying the influence of nanofluid volumetric concentration of 1% on the modified pitches of a copper corrugated tube. Likewise, the heat transmission rate is enhanced because of the increase in the Al2O3 concentration but reduced with the rise in the corrugated tube's pitch variation. Since the Al2O3 nanoparticles demonstrate a more significant influence of heat conduction in a nanofluid, their presence causes the thermal conductivity to improve proportionally with an increase in the loading of Al2O3 nanoparticles in the nanofluid. Hydrodynamic cavitation was used to disperse Al2O3 nanoparticles in water further to improve nanofluids' thermal conductivity. This enhances the nanoparticle's Brownian motion, which rises with the temperature of Al2O3 nanofluids. To increase thermal conductivity, liquid molecules make a nano-layered structure over the surface of Al2O3 nanoparticles. This allows heat to be transferred from the nanoparticles to the liquid around them, creating a homogenous suspension [13,27].

4.4. Teaching-learning-based algorithm

Changing the regular parameters and the algorithm-specific variables further reduces the effort required. Rao et al. [24] devised a unique approach in TLBO without any specific algorithm operators. Thus, an algorithm based on teaching and learning is called a "teaching-learning algorithm." The TLBO algorithm has no algorithm-specific variables, making it easier to implement and use than other population-based optimisation methods. As a result of TLBO, the convergence rate is improved since the best solution from each generation is used to modify the current solution. TLBO uses the mean value as the influencing parameter to get better results. In TLBO, the "Learner Phase" and "Teacher Phase" are distinct phases [28].

4.4.1. Teacher’s Phase

To improve students' knowledge to the highest level possible, an excellent teacher helps them to learn all they can. A superb teacher can't move students above the class mean in real-time, but they may be able to influence them to some extent in the future. It depends on the level of competence of the entire class. Based on the influencing values, this is estimated as the mean value. The best instructors will be selected as part of the teacher selection process. The heat transfer rate of the instructor determines the most effective instructor. As a result, the instructor’s expertise will more likely benefit the whole group of students. Eqn. (3) can be used to improve the performance of each learner [14].

\[ X_{t_n} = X_{t_o} + \text{random} \left( X_{b_t} - (t^*m) \right) \]  

4.4.2. Learner’s Phase

The second stage of the Multi-Objective Teaching Learning Based Optimization (MO-TLBO) algorithm requires students (learners) to engage with one another to increase their knowledge. Random communication between students allows them to expand their knowledge. A student being taught may learn new concepts from another student with more ability than them. This phase begins with students interacting with another randomly chosen string, for which randomly selected students
are preferred. A relationship between the following eqn. (4) and eqn. (5) has been established. The heat transfer rate values of the two pupils will be compared in this section of the paper. The student's heat transfer rate value exceeds the heat transfer rate value of the selected student. If the student's heat transfer rate value is more significant,

\[ X_{lns} = X_{ls} + \text{rand} \times (X_{ls} - X_{ss}) \]  
\[ X_{lns} = X_{ls} + \text{rand} \times (X_{ss} - X_{ls}) \]  

(4)

(5)

Table 3 Design Variables and their levels

<table>
<thead>
<tr>
<th>Design Variables</th>
<th>Unit</th>
<th>L1</th>
<th>L2</th>
<th>L3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch</td>
<td>mm</td>
<td>18</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Flow Rate</td>
<td>m³/h</td>
<td>0.1</td>
<td>0.15</td>
<td>0.2</td>
</tr>
<tr>
<td>Nano concentration</td>
<td>%</td>
<td>0.25</td>
<td>0.5</td>
<td>1</td>
</tr>
</tbody>
</table>

During the subsequent iteration, the output of the learner phase will be utilised as the input for the teacher phase. After a sufficient number of generations or iterations, the instructors' and learners' grades will be repeated until the requisite number of generations or iterations has been reached. This investigation selected corrugated tube pitches, fluid flow rate and Al2O3 nanofluid concentration as design variables. Three factors and three levels were determined and tabulated in table 3. There are 100 iterations, and the optimal number of students for MO-TLBO is 10. After 40 iterations, the plot below shows (fig 10) that the solution is convergent and yields optimal parameters.

Table 4 Full factorial design experimental values

<table>
<thead>
<tr>
<th>Std. Order</th>
<th>Run Order</th>
<th>Pitch (mm)</th>
<th>Flow Rate (m³/h)</th>
<th>Nano concentration (%)</th>
<th>Heat Transfer rate (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>1</td>
<td>20</td>
<td>0.15</td>
<td>0.25</td>
<td>98.2</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>18</td>
<td>0.1</td>
<td>0.5</td>
<td>98.5</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>18</td>
<td>0.1</td>
<td>0.25</td>
<td>96.5</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>18</td>
<td>0.15</td>
<td>0.25</td>
<td>104.1</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>18</td>
<td>0.1</td>
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<td>104.3</td>
</tr>
<tr>
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<td>6</td>
<td>25</td>
<td>0.2</td>
<td>0.25</td>
<td>97.5</td>
</tr>
<tr>
<td>21</td>
<td>7</td>
<td>25</td>
<td>0.1</td>
<td>1</td>
<td>97.5</td>
</tr>
<tr>
<td>23</td>
<td>8</td>
<td>25</td>
<td>0.15</td>
<td>0.5</td>
<td>97.5</td>
</tr>
<tr>
<td>24</td>
<td>9</td>
<td>25</td>
<td>0.15</td>
<td>1</td>
<td>99.1</td>
</tr>
<tr>
<td>27</td>
<td>10</td>
<td>25</td>
<td>0.2</td>
<td>1</td>
<td>103.5</td>
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<tr>
<td>20</td>
<td>11</td>
<td>25</td>
<td>0.1</td>
<td>0.5</td>
<td>88.3</td>
</tr>
<tr>
<td>22</td>
<td>12</td>
<td>25</td>
<td>0.15</td>
<td>0.25</td>
<td>94.5</td>
</tr>
<tr>
<td>6</td>
<td>13</td>
<td>18</td>
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<td>1</td>
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<td>5</td>
<td>14</td>
<td>18</td>
<td>0.15</td>
<td>0.5</td>
<td>108.3</td>
</tr>
<tr>
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<td>15</td>
<td>20</td>
<td>0.2</td>
<td>1</td>
<td>109.5</td>
</tr>
<tr>
<td>16</td>
<td>16</td>
<td>20</td>
<td>0.2</td>
<td>0.25</td>
<td>101.2</td>
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<tr>
<td>7</td>
<td>17</td>
<td>18</td>
<td>0.2</td>
<td>0.25</td>
<td>108.3</td>
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<tr>
<td>17</td>
<td>18</td>
<td>20</td>
<td>0.2</td>
<td>0.5</td>
<td>99.5</td>
</tr>
</tbody>
</table>
After the necessary number of generations have passed, the input parameter and output parameter combinations that have been optimised for the heat transfer rate are summarised in Table 4 and 5. Corrugated tube pitch of 17.88 mm, fluid flow rate of 0.198 m$^3$/h, and Al$_2$O$_3$ nanofluids concentration of 0.98% were found to be the optimal heat transfer parameters, with corresponding response parameters of the heat transfer rate of 116.45 kW.

Table 5 Optimized results of Heat Transfer rate by MOTLBO

<table>
<thead>
<tr>
<th>Pitch (mm)</th>
<th>Flow Rate (m$^3$/h)</th>
<th>Nano concentration (%)</th>
<th>Heat Transfer rate (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>17.88</td>
<td>0.198</td>
<td>0.98</td>
<td>116.45</td>
</tr>
</tbody>
</table>

5. Conclusion

This study aims to determine the heat transfer rate in a tube heat exchanger using a corrugated copper tube utilising an aluminium oxide nanofluid based on the water under laminar flow. A nanofluid of aluminium oxide in water was investigated with concentrations of 0.25%, 0.5%, and 1% by volume. The corrugated tube has been fabricated with three pitches of 25 mm, 20 mm, and 18 mm, and experimental research was done at three flow rates of 0.1 m$^3$/h, 0.15 m$^3$/h, and 0.2 m$^3$/h using deionised water and aluminium oxide nanofluid.
The heat transfer coefficient increases by 32.87%, 42.11%, and 40.29% at maximum compared to base deionised water. This was achieved in a corrugated tube pitch of 18mm and an Al₂O₃ nanofluid concentration of 1 vol.% for flow rates of 0.1 m³/h, 0.15 m³/h, and 0.2 m³/h, respectively.

Compared to the smooth copper tube, the heat transfer coefficients of 20.58%, 20.04%, and 20% were achieved at a corrugated tube pitch of 18mm and an Al₂O₃ nanofluid concentration of 1 vol.% for flow rates of 0.1 m³/h, 0.15 m³/h, and 0.2 m³/h, respectively.

At 18 mm corrugated tube pitch and one vol.% Al₂O₃ nanofluid concentration for the three different flow rates, the heat transfer coefficient increased by 26.27%, 30.74%, and 26.76%, respectively. This was in comparison to the base smooth stainless steel tube.

It was observed that as the corrugation pitch increases, heat transfer decreases. However, the heat transfer rate increased with the percentage of nanofluids concentration and flow rate.

Corrugated tube pitch of 17.88 mm, fluid flow rate of 0.198 m³/h, and Al₂O₃ nanofluids concentration of 0.98 vol.% were found to be the optimal heat transfer parameters, with a response heat transfer rate of 116.45 kW through MO-TLBO.

It is concluded that the heat exchanger containing corrugated copper tubes with pitch 17.88 mm having 0.98 vol.% of Al₂O₃ nanofluids, flowing at 0.198 m³/h, enhances the heat transfer rate between the working fluids. This configuration can be effectively used to improve the heat transfer rate in typical concentric tube heat exchangers.

References


