Experimental investigation on enhancement of heat transfer in a straight tube heat exchanger using twisted tape inserts and nano fluids- effect of turbulent and laminar flow characteristics

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Abstract. One of the most significant groups of thermal energy handling equipment utilized in industries is heat exchangers. Their particular uses include chemical processing, waste heat recovery, space heating and air conditioning, and power generation. Most people consider heat exchangers to be complicated machines. Double-pipe heat exchangers are easy to build and analyze. However, given their extensive usage in industries, their significance is unquestionable. They have undergone several improvements to impact energy, reduce material costs, and thereby mitigate environmental deterioration. In industry, heat exchangers are commonly utilized for both heating and cooling purposes. Heat passes via the dividing walls of a recuperator, a form of heat exchanger that has distinct flow routes for each fluid along its tubes. Typically, the base fluid is water, ethylene glycol or oil, and the nano-particles are composed of metals, oxides or carbides. Nanofluid's ability to increase the rate of exchanging the heat in a variety of heat devices is experimentally assessed since adding nanoparticles to the base fluid improves its thermophysical characteristics. The use of inserts and nanofluids together significantly improves heat transmission.

Keywords. Concentric tube heat exchanger, heat transfer, twisted tape inserts, nanofluids.

1 Introduction

Heat exchangers are one of the most important classes of thermal energy handling devices used in industries. Their specific applications can be found in power production, space heating and air conditioning, waste heat recovery, chemical processing etc. Heat exchangers are generally regarded as complex devices. Among them, the double pipe heat exchangers are the simplest type in construction and analysis. But their importance is no way less, since they are widely used in industries. The many modifications on them so as to affect energy, material cost savings as well as consequential mitigation of environmental degradation. Passive techniques do not require direct input of external power. They generally use surface or geometrical modifications or incorporate an insert material or additional device.

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In the case of active techniques, some form of external power is applied to achieve the desired flow modification and improvement in the rate of heat transfer. Twisted tape (TT) inserts are one of the most important passive heat transfer enhancement methods used in circular channels. The enhancement in heat transfer is due to the agitation of fluid, increase in effective flow length and mixing induced by cross stream secondary flows. Twisted tapes are identified by a parameter called “Twist ratio”.

1.1 Basic Heat Exchanger Flow Arrangements:

Two basic flow arrangements are shown in Figure 1 and 2. Parallel and counter flow provides alternative arrangements for certain specialized applications. In parallel flow both the hot and cold streams enter the heat exchanger at the same end and travel to the opposite end in parallel streams. Energy is transferred along the length from the hot to the cold fluid so the outlet temperatures asymptotically approach each other. In a counter flow arrangement, the two streams enter at opposite ends of the heat exchanger and flow in parallel but opposite directions. Temperatures within the two streams tend to approach one another in a nearly linearly fashion resulting in a much more uniform heating pattern. Parallel flow results in rapid initial rates of heat exchange near the entrance, but heat transfer rates rapidly decrease as the temperatures of the two streams approach one another. This leads to higher energy loss during heat exchange. Counter flow provides for relatively uniform temperature differences and, consequently, lead toward relatively uniform heat rates throughout the length of the unit.

![Fig. 1. Basic Flow Arrangements for Tubular Heat Exchangers](image1)

1.2 Types Of Heat Exchangers:

![Fig. 2. Classification of heat exchangers](image2)
2 Literature Review

Sivasubramaniam AP et al. (2020) [1], Heat exchangers are important devices that are commonly used in various industries such as processes, petroleum refining, chemicals, oil industries, power plants, and paper, etc. The demand for high efficiency heat exchangers has been driven by energy and material saving requirements as well as environmental challenges in the industry. In order to improve the heat exchanger performance, an increase in the heat transfer in heat exchangers is required. The counter flow heat exchanger increases the heat transfer feature of the plain tube with plain tape insert in the inner tube. To predict the Nusselt number, Reynolds number & Thermal enhancement factor based on the numerical calculation with help of ANSYS software.

Abdur M R et al. (2020) [2] stated that, Experimental Analysis for the Enhancement of Heat Transfer in a Tube Using Double Counter Twisted Tape. In this analysis heat transfer enhancement of water using double counter twisted tape has been carried out. Heat transfer coefficient, Nusselt Number, frictional coefficient has been calculated for both plain tube with and without inserts. The experimental set up consists of a long copper tube of 26.6 mm internal diameter and 30 mm outer diameter and effective length is 900 mm. The insert is 850 mm in length, 8.5 mm in width, 1.5 mm in thickness having twisted ratio 6.25. For Reynolds Number 2960-5382 Nusselt Number, friction factor and heat transfer coefficient have increased up to 63%, 1.4-1.6 times and 58.57%-65% respectively comparing with plain tube using double counter insert.

Kumar B et al. (2018) [3] stated that, Inserts are used to enhance the heat transfer rates between the two fluids in heat exchanger tubes. A variety of tube inserts such as twisted tape, wire coil, swirl flow generator has been investigated for their effect on heat transfer rates and fluid friction. This paper reviews the works pertaining to the application of different class of tube inserts in order to comprehend the prevailing mechanism of fluid flow and heat transfer. An attempt has been made to elucidate the fluid flow behavior sustained by the particular class of insert that controls the heat transfer rates across the thermal boundary layer attached to the tube wall.

Lokesh K et al. (2017) [4] stated that, a double pipe heat exchanger system is considered for studying the variation of effectiveness of the heat exchanger by inserting twisted tape. The analysis is done for different mass flow rates, different inlet temperatures for parallel and counter flow arrangements. It is observed that the effectiveness of heat exchanger in parallel flow arrangement with twisted plate is higher than the effectiveness in counter flow arrangement without twisted tapes. Hence twisted tape inserts in counter flow arrangement enhance heat transfer rate considerably there by increases effectiveness of the system at a marginal increase in pressure drop.

Zhang C et al. (2016) [5], stated that, Comprehensive and comparative experimental and numerical works done on the self-rotating and stationary twisted tapes. The heat transfer enhancement and the function of online anti-scaling and de scaling in tube can be obtained with the self-rotating twisted tapes. Mean while, the tube with self rotating twisted tapes gives the lower pressure drop. Both heat transfer coefficient and friction factor increase with the decreasing of twisted ratio. The twisted tapes combined with different modified techniques are the new development directions of heat transfer enhancement. The appropriate twisted tape modification is necessary for heat transfer enhancement with pressure loss penaltyata reasonable level.

Varun et al. (2016) [6], observed that, heat transfer augmentation using twisted tapes has been carried out. Previous experimental and numerical studies on various types of twisted tapes (based on the literature survey) were discussed. These studies reveal that the future search in the area of twisted tapes will bring more development in the heat exchanger systems. The optimum shape for twisted tapes can also be developed based on maximization of heat transfer and minimization of friction factor regarding fluid used in the system.

Alok kumar et al. (2016) [7] stated that, Comparison of some of the most commonly used insert geometries. Insert geometry selected for this comparison is collection of core fluid disturbance, surface modification and combination of both. Different geometries taken in this study include twisted tape, twisted tape with ring, circular band, and multiple twisted tapes. Twisted tape with conical rings, and
so on and used air under turbulent flow regime as working fluid. On the basis of comparison made, it is observed that, in case of "single twisted tape insert" the thermal performance factor was maximum and in the event of "twisted tape with circular ring" the overall heat transfer rate is maximum.

3 Experimental Setup

3.1 Heat Exchanger Specifications:

Concentric pipes that have been welded in series make up the concentric tube-type heat exchanger. The outermost pipe was composed of standard steel tube with an inner diameter of 0.052 meters and an outer diameter of 0.056 meters, and it has a length of 1800 cm. The inner pipe is comprised of copper with an inner diameter of 0.032 meters and an outer diameter of 0.034 meters. The annular space between the tubes is employed for transferring cold water from the supply main and hot fluid from the next-door geyser through the inner pipe. In addition, there are valves across both conduits that control how the stream flows. Thermocouples are installed in the concentric tube to monitor the temperature of the streams at the appropriate intervals along the heat exchanger.

3.2 Inserts

Inserts are additional arrangements engineered to obstruct fluid flow as well as accelerate heat transfer.

![Fig. 3. Experimental Set Up](image)

3.3 Synthesis and Characterization of Nano Particles

3.3.1 Al₂O₃ nanoparticle preparation

Granular aluminum oxide is sourced from commercial products like Avera. This Al₂O₃ powder was ground into Al₂O₃ nano particles for three hours in a high-energy, revolutionary ball mill. The ratio of the Al₂O₃ powder to the balls was taken to be 1:10. The ball-to-powder ratio and duration both affect the size of the nanoparticles. Using the law of mixing formula, 7.12, 6.60, and 5.90 grams of Al₂O₃ nanoparticles are mixed to make 0.2%, 0.4%, and 0.6% volume fractions. The mixture is then vigorously stirred with 250 millilitres of water. After 30 minutes, the aforementioned solution was gradually stirred in with 1/10th gram of polyvinyl alcohol (PVA). Al₂O₃ scattered solution is the name given to this mixture. Properties of Al₂O₃ nanofluids are presented in table 1.
Table 1: Al₂O₃ nanofluid properties

<table>
<thead>
<tr>
<th>Concentration of Volume</th>
<th>Density(ρ) (Kg m⁻³)</th>
<th>Specific Heat (Cₚ) (J kg⁻¹K⁻¹)</th>
<th>Thermal Conductivity (k) (W m⁻¹K⁻¹)</th>
<th>Viscosity (μ) Pa s</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 %</td>
<td>1057.17</td>
<td>3526.68</td>
<td>0.441</td>
<td>0.00169</td>
</tr>
<tr>
<td>0.4 %</td>
<td>1063.08</td>
<td>3505.88</td>
<td>0.447</td>
<td>0.00180</td>
</tr>
<tr>
<td>0.6 %</td>
<td>1068.99</td>
<td>3485.30</td>
<td>0.451</td>
<td>0.00189</td>
</tr>
</tbody>
</table>

3.3.2 CuO nanoparticles Preparation

Granular copper oxide (CuO) is sourced from Avera commercial goods. This CuO powder was treated for three hours in a high-energy, revolutionary ball mill to produce CuO nanoparticles. The ratio of the CuO powder to the balls was taken as 1:10. The ball-to-powder ratio and the amount of time both affect the size of the nanoparticles. The law of mixing formula is used to compute the 7.90, 7.12, and 6.20 grams of CuO nanoparticles that are mixed to make the 0.2%, 0.4%, and 0.6% volume fractions. The mixture is then vigorously stirred with 250 milliliters of water. After 30 minutes, the aforementioned solution was gradually stirred with the addition of 1/10th gram of polyvinyl alcohol (PVA). CuO-scattered solution is the name given to this mixture. Properties of CuO nanofluids are presented in table 2.

Table 2: CuO nanofluid properties

<table>
<thead>
<tr>
<th>Concentration of Volume</th>
<th>Density(ρ) (Kg m⁻³)</th>
<th>Specific Heat (Cₚ) (J kg⁻¹K⁻¹)</th>
<th>Thermal Conductivity (k) (W m⁻¹K⁻¹)</th>
<th>Viscosity (μ) Pa s</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 %</td>
<td>2080</td>
<td>3457.6</td>
<td>1.0422</td>
<td>0.001335</td>
</tr>
<tr>
<td>0.4 %</td>
<td>2088</td>
<td>3429.2</td>
<td>1.0531</td>
<td>0.002214</td>
</tr>
<tr>
<td>0.6 %</td>
<td>2095</td>
<td>3401.5</td>
<td>1.0761</td>
<td>0.003121</td>
</tr>
</tbody>
</table>

3.4 Experimental Procedure

To start the experiment, the cold water supply valve is opened and inspected the water coming out of the measurement tank. This valve can be adjusted to have a certain range of flow rates. Approximate configuration is established for each run to yield distinct flow rates. In the event that the flow rates have been established, the remainder of the run by periodically monitoring the thermocouples’ readings to see if steady conditions have already been reached and by measuring the two streams respective flow rates. Greater accuracy can be obtained with longer measurement times. One can calculate the volumetric flow rate by dividing the collected water volume by the time interval.

Once a suitable steady state has been reached, note all temperature readings and flow rates, meaning that the setup is finished if no appreciable variations are noticed. Carry out an additional trial by modifying the cold fluid flow rate. Data is collected for temperature, cold fluid flow rate etc. After the water is heated (by geyser) for five to ten minutes, the valves are turned on and continued the process until a steady condition is established. Measure the fluid temperatures, taking note of the cold fluid at the intake and outflow as well as the hot fluid temperature.

After recording the temperatures for a single mass flow rate, repeat the process to determine the temperatures for three distinct mass flow rates. The hydraulic diameter, flow area, fluid velocity, Nussle number, Reynolds number, total heat transfer coefficient, and heat transfer rate are all calibrated using the tabular data. The entire process is repeated with the counter flow, using various mass flow rates and inserts (twist ratio of 5, 3.75, 2.5 (100mm, 75mm, 50mm pitch insert), circular, and trapezoidal, as shown in Fig. 3. The Reynolds number, Nusslet number, heat transfer co-efficient U, flow area, fluid velocity, and heat transfer surface areas are all determined using calculated tabulated data. Complete the procedure with different fluids at varying mass flow rates.
4 Results and Discussion

In this chapter it is discussed about the influence of using different types of inserts in heat exchanger on characteristics of the hot and cold fluid. In the present work, I experimentally investigated heat transfer characteristics from hot fluid to cold fluid by counter flow concentric tube heat exchangers using inserts of different geometry, such as twisted tape, circular, and trapezoidal inserts, with different nanofluids as working fluids. The double pipe heat exchanger is made from straight tube with inner tube and outer tube outer diameters are 34mm and 56 mm respectively. The twisted tape inserts of 20mm diameter were fabricated. The inserts with pitches of 100mm, 75mm, and 50mm (twist ratios of 5, 3.75, and 2.5), cross-section geometry of circular and trapezoidal, have been used, and the same procedure has been continued by using two different nanofluids, i.e., Al₂O₃ and CuO, at three different concentrations (viz., 0.2, 0.4, and 0.6). The Reynolds number, Nusselt number, heat transfer coefficient (h), LMTD, and overall heat transfer coefficient (U) were compared for the above cases. The convective heat transfer coefficient of a double-pipe heat exchanger under various operating flow conditions, ranging from 50% to 100%, was determined.

4.1 Sample Calculations

Table 3 shows experimental results without inserts and nano-fluids. Sample calculations of parameters are presented.

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>Hot Fluid</th>
<th>Cold Fluid</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet Temperature</td>
<td>T&lt;sub&gt;in&lt;/sub&gt;</td>
<td>58</td>
<td>26</td>
</tr>
<tr>
<td>Outlet Temperature</td>
<td>T&lt;sub&gt;out&lt;/sub&gt;</td>
<td>43</td>
<td>31</td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>K</td>
<td>0.66</td>
<td>0.609</td>
</tr>
<tr>
<td>Specific Heat Capacity</td>
<td>C&lt;sub&gt;p&lt;/sub&gt;</td>
<td>4189</td>
<td>4178</td>
</tr>
<tr>
<td>Viscosity</td>
<td>µ</td>
<td>0.000561</td>
<td>0.000864</td>
</tr>
<tr>
<td>Density</td>
<td>ρ</td>
<td>990</td>
<td>998</td>
</tr>
<tr>
<td>Mass Flow Rate</td>
<td>M</td>
<td>0.197</td>
<td>0.0729</td>
</tr>
</tbody>
</table>

4.2 VALIDATION

4.2.1 Comparison Between Numerical And Experimentation Work

The validation process ensures that the numerical model accurately represents the physical behavior of the concentric tube heat exchanger under specified conditions. It contributes to the credibility and reliability of the computational model for future applications and analyses. Continuous collaboration between numerical modelers and experimentalists is crucial for refining the models and improving the overall understanding of the system. In order to analysis and validate the experimental and simulation value of plane twist tape with 2.5 twist ratio inserts utilized to examine performance characteristics at CuO nanofluid concentration 0.6% with 0.072 kg/sec flow rate as cold fluid and 0.192 kg/sec hot fluid. As has been mentioned above the investigation of PTT using numerical method the PTT with 2.5 twist ratio gives the higher performance. There is no swirl flow and minimum contact area of the fluid mixing as a result decreases performance of fluid. As inserts improve the heat transfer enhancement and makes twist on insert generates additional flow through the twists. In this present work plane twisted tape insert was used to augment additional transfer of heat than plane tube.
As a twist ratio with 2.5 create on the insert were enhanced higher heat transfer than that the remaining inserts. An experimental result of Reynold’s number, Nusselt value, LMTD and overall heat transfer coefficient.
coefficient were compared by CFD with Experimentation value is shown figure 4. The Reynold’s number value of experimental and CFD value for the PTT with twist ratio 2.5 shown in figure 4(a). It has been indicating that the Reynold’s number of experimental values was well bonded with the CFD value. An experimental value was fitted within the 2.58% of the CFD value. An experimental value of Nu fitted within the -2.61% compared by means of CFD value of Nu. The experimental value was very closely agreed with predicted Nusselt value. The LMTD value of experimental and CFD value of the PTT with 2.5 shown in figure 4(c). It has been indicating that the friction factor experimental value was well bonded with the predicted value PTT with 2.5 twist ratio. An experimental value was fitted within the -2.56% of the CFD value. The figure 4(d) given the variation of overall heat transfer characteristics of the PTT with twist ratio 2.5 by CFD and Experimentation. An experimental value of overall Heat transfer coefficient fitted within the 2.6% compared by means of CFD value of overall heat transfer coefficient. The experimental value was very closely agreed with CFD overall heat transfer coefficient value.

5 Conclusions

Experiments are conducted with Al₂O₃ and CuO nanofluids through a straight tube heat exchanger. Inserts such as circular and trapezoidal inserts and twisted tape with twist ratios of 2.5, 3.75, and 5 (100 mm, 75 mm, and 50 mm pitch) have been utilized in conjunction with nanofluids. Numerical investigations are also carried out using computational fluid dynamics (CFD) simulation for finding the exact enhancement of heat transfer in the heat exchanger using Al₂O₃ and CuO nanofluids at 0.2, 0.4 and 0.6 concentrations along with the twisted tape, circular and trapezoidal inserts. The results show that Reynolds number and particle concentration affect the flow characteristics and ability to transmit heat. Significant findings have been made, which are summed up as follows.

Numerical investigation

Numerical study on enhancement of heat transfer in a straight tube heat exchanger caused by inserts and nano fluids was done. The different types twisted tape provided better thermal performance than that the without inserts, under different flow condition. Various types of twisted tape inserts are used to investigate numerically. In this present work computational fluid dynamics (CFD) analysis with Ansys, heat transfer and flow analysis was used to investigate the various parameters. Among the variant model twisted tape insert with 2.5 twist ratio along 0.6% of CuO given better performance.

- The Reynolds number for a 0.6% volume concentration of Al₂O₃ at 0.072 kg/sec with a TR2.5 insert is 15870.02, whereas the value for plane water is 12798.91. That means Al₂O₃ Nanofluid with 0.6% shows 23.99% high when compared to base fluid. Similarly for 0.6% of CuO nanofluid the Reynolds number is 16027.166 at same conditions which is 25.22% high compare to base fluid.
- The Nusselt number for a 0.6% volume concentration of Al₂O₃ at 0.072 kg/sec with TR2.5 insert is 104.8733, whereas the value for plane water is 91.55. This shows that Al₂O₃ Nanofluid with 0.6% shows 14.55% high when compared to base fluid. Similarly for 0.6% of CuO nanofluid, the Nusselt number is 105.68 at same conditions which is 15.43% high compare to base fluid.
- The overall heat transfer coefficient for a 0.6% volume concentration of Al₂O₃ at 0.072 kg/sec with a twisted tape insert along twist ratio 2.5 is 1548.933 W/m²K whereas the value for plane water is 1187.18 W/m²K. That means Al₂O₃ Nanofluid with 0.6% shows 23.99% when compared to base fluid. Similarly for 0.6% of CuO the overall heat transfer coefficient is 1828.332 at same conditions which is 54% high compare to base fluid.

Experimental Investigation

- As the fluid flow rate rises, the dispersion of the nanoparticles into the base fluid (water) raises the average heat transfer coefficient.
Experimental studies were conducted to determine the total heat transfer coefficient for both the base fluid and the nanofluids (Al$_2$O$_3$, CuO).

The Reynolds number for a 0.6% volume concentration of Al$_2$O$_3$ at 0.072 kg/sec with a twisted tape insert (twist ratio 2.5) is 15393, whereas the value for water is 11958.8. Al$_2$O$_3$ Nanofluid with 0.6% has an increase of 28.71% when compared to water as the base fluid. The Reynolds number is 15621 at a volume concentration of 0.6% CuO at 0.072 kg/sec with a twisted tape insert (twist ratio 2.5). When compared to base fluid water, an increase of 26.2% was achieved using 0.6% CuO nanofluid.

The overall heat transfer coefficient is 1502.36 W/m$^2$K at a volume concentration of 0.6% Al$_2$O$_3$ at 0.072 kg/sec with a twisted tape insert (twist ratio 2.5), whereas it is 1158.23 W/m$^2$K for water. When compared to base fluid water, an increase of 29.71% was achieved using 0.6% Al$_2$O$_3$ nanofluid. Similarly with 0.6% of CuO in 0.072 kg/sec with a twisted tape insert (twist ratio 2.5), the overall heat transfer coefficient is 1782 W/m$^2$K. A maximum enhancement of 53.85% was obtained with 0.6% CuO nanofluid compared to base fluid water.

The deviation between the experimental and numerical result was observed that maximum + 2.1% to 3.1% of Reynold’s number and overall heat transfer coefficient respectively.

References