Heat transfer analysis of Al₂O₃ nanofluid in a tube with two different twist inserts is experimentally investigated. Experiments are conducted with water and nanofluid of 0.1 % particle volume with various volume flow rate for plain tube, tube with twist insert having knurling impressions and tube with twist insert having holes at equal intervals under forced convection. It is seen that the heat transfer rate increases with volume flow rate. The Reynolds Number increases with volume flow rate and is high for water + 0.1 % Al₂O₃ nanofluid than water. But the Nusselt Number is low for water + 0.1 % Al₂O₃ nanofluid than water. However from the figures it can be seen that the value of heat transfer rate of water + 0.1% Al₂O₃ nanofluid is high with various volume flow rates as compared to heat transfer rate value of water for plain tube, tube with twist inserts having knurling impressions and tube with twist insert having holes at equal intervals for the same correlations. Also the heat transfer coefficient of water + 0.1 % Al₂O₃ nanofluid is high as compared to base fluid because the addition of 0.1 % volume concentration of Al₂O₃ nanofluid increases the heat transfer characteristics of base fluid (water). But we found that the twist insert having holes at equal intervals has a significant effect on heat transfer than plain tube and twist insert having knurling impressions.

Keywords: Al₂O₃ nanofluid, twist inserts with holes, knurling impressions, Circular tube, Heat Transfer Analysis

INTRODUCTION

Nanofluid is a fluid containing nanometer-sized particles, called nanoparticles. These fluids are engineered colloidal suspensions of nanoparticles in a base fluid. The nanoparticles used in nanofluids are typically made of metals, oxides, carbides, or carbon nanotubes. Common base fluids include water, ethylene glycol and oil. Nanofluids have novel properties that make them potentially useful in many applications in heat transfer, including microelectronics, fuel cells, pharmaceutical processes, and hybrid - powered engines, engine cooling / vehicle thermal management, domestic refrigerator, chiller, heat exchanger, nuclear reactor coolant, in grinding, machining, in space technology, defense and ships, and in boiler flue gas temperature reduction. They exhibit enhanced thermal conductivity and the convective heat transfer coefficient compared to the base fluid. Knowledge of the rheological behavior of nanofluids is found to be very critical in deciding their suitability for convective heat transfer applications. A lot of work has been done recently on the forced convective heat transfer of nanofluids in pipe flow.

L. Syam Sundar et.al. investigated experimentally the fully developed laminar convective heat transfer and friction factor characteristics of different volume concentrations Al₂O₃ nanofluid in a plain tube and fitted with different twist ratios of twisted tape inserts. They conducted the experiments with water and nanofluid in the range of 700 < Re < 2200, particle volume concentration of 0 < φ < 0.5%, twisted tape twist ratios of 0 < H / D < 15. Nanofluid heat transfer coefficient was high compared to water and further heat transfer enhancement was observed with twisted tape inserts. Pressure drop is slightly increase with the inserts, but comparatively negligible. They developed the generalized regression equation based on the experimental data for the estimation of Nusselt number and friction factor for water and nanofluid in a plain tube and with twisted tape inserts. H. Almohammedi Sharma et.al. investigated experimentally the convective heat transfer coefficient and pressure drop of Al2O3/water nanofluid in laminar flow regime under constant heat flux conditions inside a circular tube. Al₂O₃/water nanofluid with 0.5% and 1% volume concentrations with 15 nm diameter nanoparticles were used as working fluid. Measurements show the average heat transfer coefficient enhanced about 11-20% with 0.5% volume concentration and increased about 16-27% with 1% volume concentration compared to distilled water. In addition, the average ratio of (f/fbf) was about 1.10 for 0.5% volume concentration.

Abdulhassan Abd. K et.al.measured the pressure drop and convective heat transfer coefficient of water – based AL(25nm), Al₂O₃ (30nm) and CuO (50nm) Nanofluids flowing through a uniform heated circular tube in the fully developed laminar flow regime. The experimental results show that the data for Nanofluids friction factor show a good agreement with analytical prediction from the Darcy's equation for single-phase flow. The study also
demonstrated that the amount of the increase in heat transfer coefficient for three types of Nano fluid is Al, Al$_2$O$_3$, and CuO – Water and these ratios are respectively (45%, 32%, 25%) with insulation and without insulation (36%, 23%, 19%), and the statement of any of the cases the best increase in heat transfer has been proven that using insulation is better than not using it. Eldwin Djajadiwinata et al. assessed experimentally the turbulent forced convective heat transfer and pressure drop of 0.01 vol. % CuO-water nanofluid. The nanofluids were made flow into a heated horizontal tube under uniform constant heat flux within Reynolds number range of 11,500 to 32,000. They found that the nanofluid’s Nusselt number and friction factor, which represent the heat transfer rate and pressure drop, respectively, are close to those of water. Hence, there is no anomaly due to the dispersed nanoparticles within the water.

PREPARATION OF NANOFLUIDS

Some properties of hydrophilic rod-like Al$_2$O$_3$ nanoparticles (AF-alumina type) and base fluid (water) which have been used for assessing the nanofluid properties are tabulated in Table 1. The AF alumina type nanoparticle is rod-like and because of its cylindrical shape and elongation, it has a better heat conduction through the fluid rather than spherical nanoparticles.

<table>
<thead>
<tr>
<th>Material properties</th>
<th>AF alumina</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific heat (J kg$^{-1}$ K$^{-1}$)</td>
<td>765</td>
<td>4179</td>
</tr>
<tr>
<td>Density (kgm$^{-3}$)</td>
<td>3800</td>
<td>997.1</td>
</tr>
<tr>
<td>Thermal conductivity (Wm$^{-1}$ K$^{-1}$)</td>
<td>40</td>
<td>0.605</td>
</tr>
<tr>
<td>Size</td>
<td>40 – 50 nm</td>
<td></td>
</tr>
</tbody>
</table>

TEST SECTION

A straight tube made up of stainless steel with 1000 mm length, 10 mm internal diameter, and 12 mm outer diameter was used as the test section. The insert which is made up of stainless steel is made in the laboratory from a 0.5 mm thick and 1000 mm length with a hole at equal intervals. The twist insert is as shown in figure.

Twist tape inserts are used to increase the turbulence by increasing the circulation effects. Twist tape inserts were made from the laboratory. The specifications of tape inserts are listed below.

<table>
<thead>
<tr>
<th>Table 2. Core data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particular</td>
</tr>
<tr>
<td>Twist tape with knurling impressions</td>
</tr>
<tr>
<td>Twist tape with holes</td>
</tr>
</tbody>
</table>
EXPERIMENTAL SET UP

The schematic diagram of the experimental setup is shown in fig.3.

Figure 3 Schematic view of experimental setup

It consists of a calming section, test section, pump, cooling unit, and a fluid reservoir. The test fluid is directed from the reservoir to the calming section and then to the test section using a pump. There is a valve and a bypass valve used to control the flow rate. The flow rate is adjusted to the required rate in the flow meter. The fluid after passing through the heated section flows through a riser section and then through the cooling unit and finally it is collected in the reservoir. The test section is heated uniformly by the electrical heating wire, attached to an auto-transformer, by which the heat flux can be varied by varying the voltage. Calibrated RTD sensors are used to measure the inlet, outlet, and surface temperatures at five different locations. The pressure drop across the test section is measured using a U tube manometer with mercury as the manometric fluid. An autotransformer is used to control the surface temperature of heater. A plastic container of 5 liter capacity is used as the fluid reservoir. The experimental study on heat transfer and friction characteristics of Al$_2$O$_3$/water hybrid nanofluid is carried out in a straight circular tube having specifications as listed below in table 3.

Table 3. Specifications of Test section

<table>
<thead>
<tr>
<th>Metal of construction</th>
<th>Stainless steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube ID</td>
<td>10 mm</td>
</tr>
<tr>
<td>Tube OD</td>
<td>12 mm</td>
</tr>
<tr>
<td>Heat transfer length</td>
<td>1000 mm</td>
</tr>
<tr>
<td>Entrance length</td>
<td>1000 mm</td>
</tr>
</tbody>
</table>

The test section is wound with ceramic beads coated electrical SWG Nichrome heating wire of resistance 120 $\Omega$. Over the electrical winding a thick insulation is provided using glass wool to minimize heat loss. Thermo wells are mounted on the test section at axial positions in mm of 50, 100, 300, 700 and 950 from the inlet of the test section for installing temperature sensors for outside wall measurements. Thermo wells are also mounted at a distance of 15 mm outside the inlet and exit sections for placing fluid temperature sensors. All RTDs used for temperature measurements were calibrated. The experiment was conducted with water in the Reynolds number range of 6000-18000 for turbulent flow respectively. Centrifugal pump was used to pump nanofluid from the reservoir. The heater was switched on and autotransformer was adjusted to 160 volts. A valve is used to control the flow rate of the nanofluid. The heat flux was set by adjusting the electrical voltage with the help of an auto transformer, and constant heat flux was allowed to continue till the steady state is reached. The water is allowed to pass through the testing section. The flow rate is made to set at 120 lit/hr in the flow meter. When the steady state is reached, the inlet, outlet and surface temperatures of tube were noted down from the temperature monitor panel. The water after passes through the test section was made to flow through the cooling unit where the water was getting cooled so as to allow the water to circulate again. Now the flow rate was adjusted to 180 lit/hr in the flow meter and the same procedure was followed for taking readings. This procedure was followed for various flow rates of water and the readings were noted down. Now the twist inset with knurling impressions was inserted inside the plain tube to conduct the experiment. The same procedure was followed for twist insert with holes at equal intervals. The experiments were conducted with plain tube, tube with twist tape with knurling impressions and twist tape with holes at equal intervals.
DATA AND PROCESSING

Thermo Physical Properties of Nanofluids: The density of $\text{Al}_2\text{O}_3$/water nanofluid can be calculated using mass balance as

$$\rho_{nf} = (1-\phi)\rho_{bf} + \phi\rho_{np}$$  \hspace{0.2cm} (1)

where $\rho_{np}$ and $\rho_{bf}$ are the densities of the nanoparticles and base fluid, respectively, and $\phi$ is volume concentration of nanoparticles.

According to the concept of solid-liquid mixture, the specific heat of nanofluids is given by following

$$C_{p_{nf}} = (1-\phi)\rho_{bf}c_{p_{bf}} + \phi\rho_{np}c_{p_{np}}$$  \hspace{0.2cm} (2)

where $c_{p_{np}}$ and $c_{p_{bf}}$ are the heat specifics of the nanoparticles and base fluid, respectively. One well-known formula for computing the thermal conductivity of nanofluid is expressed in the following form:

$$k_{nf} = 1 + 8.73\phi$$  \hspace{0.2cm} (3)

RESULTS AND DISCUSSIONS

VARIATION OF HEAT TRANSFER COEFFICIENT WITH VOLUME FLOW RATE

In order to compare our experimental results with the values that are obtained for water and water + 0.1 % $\text{Al}_2\text{O}_3$ Nanofluid, some graphs are plotted for which the experiment is conducted for plain tube, tube with insert having knurling impressions and tube with insert having holes at equal intervals at different volume flow rates for two different working fluids. The graphs plotted below show the variation of Heat Transfer Coefficient with various volume flow rate for two different working fluids.

Figure 5 Variation of ‘h’ with different volume flow rates for plain tube

Figure 6 Variation of ‘h’ with different volume flow rates for tube with twist insert having knurling impressions

Figure 7 Variation of ‘h’ with different volume flow rates for tube with twist insert having holes at equal intervals

Figure 8 Variation of ‘h’ with ‘Re’ for plain tube
Figure 5, 6 and 7 shows the variation of heat transfer coefficient obtained experimentally for water and water + 0.1% Al₂O₃ nanofluid with various volume flow rates. It is seen that the heat transfer coefficient increases with volume flow rate. However from the figures it can be seen that the value of heat transfer coefficient of water + 0.1% Al₂O₃ nanofluid is high for various volume flow rates as compared to heat transfer coefficient value of water for the same correlations for plain tube, tube with insert having knurling impressions and tube with insert having holes at equal intervals. So it can be concluded that with increase in volume flow rate, the heat transfer coefficient of water + 0.1% Al₂O₃ nanofluid increases than water for plain tube as well as for tube with two different inserts.

**VARIATION OF HEAT TRANSFER COEFFICIENT WITH REYNOLDS NUMBER**

In order to compare our experimental results with the values that are obtained for water and water + 0.1% Al₂O₃ Nanofluid, some graphs are plotted for which the experiment is conducted for plain tube, tube with insert having knurling impressions and tube with insert having holes at equal intervals at different volume flow rates for two different working fluids. The graphs plotted below show the variation of Heat transfer coefficient with Reynolds Number with various volume flow rate for two different working fluids.

![Figure 8 Variation of ‘h’ with ‘Re’ for plain tube](image8.png)

![Figure 9 Variation of ‘h’ with ‘Re’ for tube with twist insert having knurling impressions](image9.png)

![Figure 10 Variation of ‘h’ with ‘Re’ for tube with twist insert having holes at equal intervals](image10.png)

Figure 8, 9 and 10 shows the variation of heat transfer coefficient obtained experimentally for water and water + 0.1% Al₂O₃ nanofluid with Reynolds Number. It is seen that the heat transfer coefficient increases with Reynolds Number. However from the figures it can be seen that the value of heat transfer coefficient of water + 0.1% Al₂O₃ nanofluid is high as compared to heat transfer coefficient value of water for the same correlations for plain tube, tube with insert having knurling impressions and tube with insert having holes at equal intervals.

**VARIATION OF NUSSELT NUMBER WITH REYNOLDS NUMBER**

In order to compare our experimental results with the values that are obtained for water and water + 0.1% Al₂O₃ Nanofluid, some graphs are plotted for which the experiment is conducted for plain tube, tube with insert having knurling impressions and tube with insert having holes at equal intervals at different volume flow rates for two different working fluids. The graphs plotted below show the variation of Nusselt Number with Reynolds Number with various volume flow rate for two different working fluids.

![Figure 11 Variation of ‘Nu’ with ‘Re’ for plain tube](image11.png)

![Figure 12 Variation of ‘Nu’ with ‘Re’ for tube with twist insert having knurling impressions](image12.png)
Figure 13 Variation of ‘Nu’ with ‘Re’ for tube with twist insert having holes at equal intervals

Figure 14 Variation of ‘Nu’ with ‘Re’ for plain tube

Figure 11, 12, and 13 shows the variation of Nusselt Number with Reynolds Number obtained experimentally for water and water + 0.1% Al₂O₃ nanofluid with various volume flow rates for plain tube, tube with insert having knurling impressions and tube with holes at equal intervals. It is seen that the Nusselt Number increases with volume flow rate. However from the figures it can be seen that the value of Nusselt Number of water is high for various volume flow rates as compared to heat transfer coefficient value of water + 0.1% Al₂O₃ nanofluid for the same correlations. So it can be concluded that with increase in volume flow rate, the Nusselt Number for water is higher than water + 0.1% Al₂O₃ nanofluid for almost same Reynolds Number.

VARIATION OF FRICTION FACTOR WITH REYNOLDS NUMBER

In order to compare our experimental results with the values that are obtained for water and water + 0.1% Al₂O₃ Nanofluid, some graphs are plotted for which the experiment is conducted for plain tube, tube with insert having knurling impressions and tube with insert having holes at equal intervals at different volume flow rates for two different working fluids. The graphs plotted below show the variation of Friction factor with Reynolds Number obtained experimentally for water and water + 0.1% Al₂O₃ nanofluid with various volume flow rate for plain tube, tube with insert having knurling impressions and tube with insert having holes at equal intervals at different volume flow rates for two different working fluids.

Figure 15 Variation of ‘Nu’ with ‘Re’ for tube with twist insert having knurling impressions

Figure 16 Variation of ‘Nu’ with ‘Re’ for tube with twist insert having holes at equal intervals

Figure 14, 15 and 16 shows the variation of Friction factor with Reynolds Number obtained experimentally for water and water + 0.1% Al₂O₃ nanofluid with various volume flow rates for plain tube, tube with insert having knurling impressions and tube with holes at equal intervals. It is seen that the friction factor decreases with increase in Reynolds Number. However from the figures it can be seen that the value of Friction factor of water is high for various volume flow rates as compared to heat transfer coefficient value of water + 0.1% Al₂O₃ nanofluid for the same correlations. So it can be concluded that with increase in volume flow rate, the friction factor for water is higher than water + 0.1% Al₂O₃ nanofluid.

CONCLUSION

The experiment is conducted to determine the heat transfer characteristics of Al₂O₃ nanofluid in a plain tube, tube with twist insert having knurling impressions and tube with twist insert having holes at equal intervals at different volume flow rates. The same procedure is followed for base fluid (water) at the same correlations. The Reynolds Number increases with volume flow rate and is high for water + 0.1% Al₂O₃ nanofluid than water. But the Nusselt Number is low for water + 0.1% Al₂O₃ nanofluid than water. It is found that the heat transfer coefficient of water + 0.1% Al₂O₃ nanofluid increases with increasing volume flow rate. Also the heat transfer coefficient of water + 0.1% Al₂O₃ nanofluid is high as compared to base fluid because the addition of 0.1% volume concentration of Al₂O₃ nanofluid increases the heat transfer characteristics of base fluid (water) for plain tube, tube with twist inserts having knurling impressions and tube with twist insert having holes at equal intervals.
In addition to this it is seen that the friction factor also decreases with increase in Reynolds Number for different volume flow rate. And also it can be seen that the friction factor for water is higher than friction factor for water + 0.1 % Al₂O₃ nanofluid in a plain tube, tube with twist insert having knurling impressions and tube with twist insert having holes at equal intervals at different volume flow rates. But we found that the twist insert having holes at equal intervals has a significant effect on heat transfer than plain tube and twist insert having knurling impressions.

REFERENCES


