Heat Transfer Enhancement in Double Pipe Heat Exchanger by Alumina – Water Nanofluid

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Abstract - Fluid heating and cooling plays an important role in many industries includes thermal power stations, production processes, petrochemical and electronic components. The heat transfer enhancement methods in different processes are abundant. Most of these methods are based on structure variation, extended surfaces fins. These Enhancing techniques hardly meet the ever increasing requirement for heat transfer and the compactness of the devices in processes involving electronic chips, laser applications or high-energy devices. In this regard improvement of the thermal properties of energy transmission fluids has become one of the methods of augmenting heat transfer. Therefore, fluids with suspended solid particles are expected to have better heat transfer properties compared to conventional fluids. So far due to associated technological problems, the majority of studies on heat transfer have been with suspensions of millimeter or micron-sized particles. Such large particles cause problems such as settlement, abrasion of surfaces due to flow, clogging in flow channels in heat transfer equipments.

The present work is directed towards estimation of heat transfer coefficient and Nusselt number for Al₂O₃ of diameter 47 nm with water nanofluid in a Plain concentric double pipe counter flow heat exchanger at different volume concentrations from 0.01%, 0.02% and 0.03% are measure experimentally. The experimental results of nanofluids under different volume concentrations are compared with base fluid Water. The use of Al₂O₃ nanoparticles as the dispersed phase in water can significantly enhance the convective heat transfer in the transition flow, and the enhancement increases with increase in Reynolds number, as well as particle concentration.

Key Words: Nusselt Number, heat transfer coefficient, Reynolds Number, Al₂O₃ Nanofluid, LMTD, Thermal conductivity.

1. INTRODUCTION

Less weight fractions of nanoparticles, when dispersed and suspended stably in base fluid medium, provide drastic enhancements in the thermal properties of base fluids. This nanofluid technology is given primary importance where thermal engineering and nanotechnology meet together, has developed largely over the past decade. The vital role of nanofluids is to attain the highest possible thermal properties with low particle weight fractions by uniform dispersion and stable suspension of nanoparticles in base fluid medium. In order to achieve this goal, it is crucial to determine the enhancement of thermal energy transport in liquids. Several engineers and scientists, in the growing nano-fluid era, have performed research breakthrough by investigating unexpected thermal properties of nanofluids and also nanofluid technology even offers a vital part for the development of compact and cost effective cooling systems. Within the realm of thermal science, nanofluids are developed for their inexplicably enhanced thermal conductivities, which provide the concept of utilizing nanofluids as heat transfer fluids. The improved thermal properties of nanofluids provide a better insight into an enormous innovation for heat transfer intensification, which is of major importance to industrial sectors including power generation, transportation, and thermal therapy for cancer treatment, micro manufacturing, metallurgical and chemical sectors, as well as cooling, heating and air conditioning.

1.1 Materials Used

Nanofluids are two phase mixtures engineered by dispersing nanometer sized particles with sizes ranging below 100 nm in base fluids. The nanometer sized particles which are used for the dispersion in base fluids are nanoparticles, nanofibers, nanotubes, nanowires and nanorods. Materials generally used as nanoparticles include metal oxides (e.g., alumina, silica, zirconia, titania), oxide ceramics (e.g. Al₂O₃, CuO), chemically stable metals (e.g. gold, copper), carbon in various forms (e.g., diamond, graphite, carbon nanotubes, fullerene) metal carbides (e.g. SiC) and functionalized nanoparticles. The base fluid types include oils, water, organic liquids such as glycols, refrigerants, polymeric solutions, bio fluids, lubricants and other common liquids. From the available nano materials we have taken the Aluminium oxide (Al₂O₃) because of availability and cost.
Table 1: Properties of water and Aluminum oxide [10]

<table>
<thead>
<tr>
<th>S.No</th>
<th>Property</th>
<th>Units</th>
<th>Water</th>
<th>Alumina Oxide($\text{Al}_2\text{O}_3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Specific heat (C)</td>
<td>J/Kg K</td>
<td>4179</td>
<td>765</td>
</tr>
<tr>
<td>2</td>
<td>Density ($\rho$)</td>
<td>Kg/m$^3$</td>
<td>997.1</td>
<td>3970</td>
</tr>
<tr>
<td>3</td>
<td>Thermal conductivity (K)</td>
<td>W/m K</td>
<td>0.65</td>
<td>40</td>
</tr>
</tbody>
</table>

2. EXPERIMENTAL SETUP

2.1 Fabrication

The experimental set up fabricated as per design of heat exchanger. Four temperature indicators are used to measure inlet and outlet temperatures. The pipe connections are made to connect pump with Heat exchanger for recirculating the nano fluid (cold fluid) which is receiving heat from hot fluid. The Nano fluid at outlet of Heat exchanger is discharged into collecting tank from which the pump sucks the nano fluid. The collecting tank is provided with Evaporative cooling system to maintain the constant temperature of nano fluid.

2.2 Preparation of Nanofluid

Preparation of nanofluid is the most important step. Nanoparticles $\text{Al}_2\text{O}_3$ of particles diameter size 47 nm were purchased from Aarshdhattu Green nano Technologies India private limited Company. To the base fluid (water) $1/10^{th}$ of the Nano particles, surfactant Nonident NP40 is added with nano particles of concentrations, at 0.01%, 0.02%, 0.03%. nanofluid is prepared with the help of mechanical stirrer with electrical motor of 200 rpm. It was found that the nanofluid prepared with this method can be stable for four hours.

3. Experimentation Procedure

3.1 Formulae to calculate properties of nanofluid

The effective properties of nanofluids like density, specific heat, thermal conductivity, and viscosity are to be calculated according to the mixing theory.

1. The density of the nanofluid is calculated by using Pak and Cho correlation [1]

$$\rho_{nf} = \phi \rho_p + (1-\phi)\rho_w$$

Where $\rho_{nf}$ is the density of nanofluid, $\rho_p$ is the density of nano particle, $\rho_w$ is the density of water and $\phi$ is the volume concentration.

2. The viscosity of nanofluids less than 5% is calculated by using the Drew and Passman formula [1]

$$\mu_{nf} = \mu_w (1 + 2.5\phi)$$

Where $\mu_{nf}$ is the viscosity of nanofluid, $\mu_w$ is the viscosity of water.

3. Specific heat of nanofluid is calculated by using the Xuan and Roetzel correlation [1]
\[ C_{pnf} = \varnothing C_p + (1 - \varnothing) C_w \]

Where \( C_{pnf} \) is the heat capacity of nanofluid, \( C_p \) is the heat capacity of nano particle, \( C_w \) is the heat capacity of water.

4. Thermal conductivity of nanofluid is calculated by using the Hamilton Crosser correlation [2]

\[ K_{nf} = \left[ K_p + \frac{\varnothing}{K_p} \left( \frac{2K_f + \varnothing(K_f - K_p)}{K_p - \varnothing(K_f - K_p)} \right) \right] \times K_f \]

Where \( K_{nf} \) is the thermal conductivity of nanofluid, \( K_p \) is the thermal conductivity of nano particle, \( K_f \) is the thermal conductivity of water.

3.2 Experimental Formulae

1. Heat energy (hot fluid) \( (Q_h) = m_h C_h(T_{hi} - T_{ho}) \)
   - Where \( m_h = \) mass of hot fluid (kg)
   - \( C_h = \) specific heat of hot fluid (J/Kg.k)
   - \( T_{hi} = \) inlet temperature of hot fluid (k)
   - \( T_{ho} = \) outer temperature of hot fluid (k)

2. Heat energy (cold fluid) \( (Q_c) = m_c C_c(T_{c0} - T_{ci}) \)
   - Where \( m_c = \) mass of cold fluid (kg)
   - \( C_c = \) specific heat of cold fluid (J/Kg.K)
   - \( T_{c0} = \) outlet temperature of cold fluid (k)
   - \( T_{ci} = \) inlet temperature of cold fluid (k)

3. Average Heat transfer \( Q_{avg} = \frac{Q_h + Q_c}{2} \)

4. Convective heat transfer coefficient \( (h_{exp}) \)
   - \( h_{exp} = \frac{U}{A_0 \Delta T_{LMTD}} \)
   - \( \Delta T_{LMTD} = \frac{(T_{hi} - T_{co}) - (T_{ho} - T_{ci})}{\ln[(T_{hi} - T_{co})/(T_{ho} - T_{ci})]} \)
   - \( A_0 = \pi D_0 L \)
   - \( D_0 = \) outer diameter of heat exchanger tube
   - \( L = \) length of heat exchanger tube

5. Nusselt Number \( (Nu) \): 
   - \( Nu = h_{exp} \times D_0 / k \)
   - Where \( K = \) Thermal conductivity of fluid

6. Reynolds number \( (Re) \): 
   - \( Re = \rho V D_0 / \mu \)
   - Where \( \rho = \) density of fluid (Kg/m\(^3\))
   - \( D_0 = D_2 - D_1 \)
   - \( D_2, D_1 = \) outer and inner diameter of Heat exchanger
   - \( \mu = \) dynamic viscosity (N.s/m\(^2\))

7. Volume concentration of nanofluid:
   - \( = \) volume of Aluminium / (volume of Aluminium + volume of water)
   - \( = \frac{(w/\rho)_{Al2O3}}{(w/\rho)_{Al2O3} + (w/\rho)_{H2O}} \)

- for 0.01% volume concentration we mix 7 grams of Aluminium oxide Nanoparticles in 25 litres of water (base fluid)
- for 0.02% > 14 grams of Al\(_2\)O\(_3\)
- for 0.03% > 21 grams of Al\(_2\)O\(_3\)

4. Results and Discussions

The experimentation is initially done with water as the working fluid and the experimental convective heat transfer coefficient at the entire region of the tube was estimated. The test section is well designed to maintain counter flow direction between hot and Nano fluids either in the tubes of heat exchanger. Overall heat transfer coefficients in the outer region are estimated based on the logarithmic mean temperature distribution. The Convective heat transfer coefficient enhancement for 0.03% nanofluid with the base fluid is 47.53%

Nanofluids of different concentrations were introduced into the heat exchangers and the experimental overall heat transfer coefficient is estimated. A maximum of 73.94 enhancement was observed for 0.03% nanofluid by comparing with the base fluid in between 1 LPM and 4 LPM respectively between inner and outer regions.

Fig 5: It is observed that the thermal conductivity and Reynolds number are increasing with the increase of volume concentration of nanofluid and also Effectiveness increases.

Fig 6: shows the experimental results of water and different concentrations of nanofluid. It is observed that heat transfer coefficient increases with the increase in concentration of nanofluid compared to the base fluid.
Fig 6: heat transfer coefficient vs Reynolds number

Fig 7: shows the experimental results of water and different concentrations of nanofluid. It is observed that overall heat transfer coefficient increases with the increase in concentration of nanofluid compared to the base fluid.

Fig 7: Average heat transfer vs Reynolds number

Fig 8: shows the experimental results of water and different concentrations of nanofluid. It is observed that average heat transfer increases with the increase in concentration of nanofluid compared to the base fluid.

Fig 8: Reynolds number vs Overall heat transfer coefficient

Fig 9: shows the experimental results of water and different concentrations of nanofluid. It is observed that Effectiveness increases with the increase in concentration of nanofluid compared to the base fluid.

Fig 9: Volume concentration vs Effectiveness

5. Conclusion

The heat transfer coefficient and Effectiveness for water based Al$_2$O$_3$ Nanofluid at different volume concentrations were measured experimentally. It is observed that the dispersion of nanoparticles in all the base fluids, increases heat transfer coefficient and Effectiveness and it further increases with increase of particle volume concentration.

The heat transfer coefficient enhancement for Al$_2$O$_3$– water nanofluid is 73.94 % for 1 LPM and 65.25 % for 4 LPM by comparing the 0.03% with water. It indicates that heat transfer coefficient of nanofluids increases with increase of Reynolds number compared to single phase fluid. Heat transfer coefficient increases with increase of volume concentration of nanoparticles in water as base fluid.

REFERENCES


BIOGRAPHIES

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