Heat Transfer Augmentation by using Metallic Nanoparticles at Different Concentrations in a Counter Flow Heat Exchanger

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ABSTRACT

Heat exchangers are essential devices for almost all industrial and automobile applications. In this paper, the heat transfer and pressure drop characteristics of the pure water and the water mixed with copper oxide, Iron oxide and aluminum oxide with different mass concentration based nanofluid flowing in a horizontal circular pipe under constant heat flux condition are studied. The nanofluids are made in three different mass concentrations i.e. 0.5%, 1.0%, 1.5% and 2%. The results show that the thermal conductivity is increases with increasing temperature and mass concentration.

Keywords--- Nanofluid, Heat Transfer Characteristics, Double Pipe Heat Exchanger, mass concentration percentage, pressure drop,

Nomenclature

\( m \) Mass flow rate \( (kg/s) \)
\( Q \) Heat transfer rate \( (W) \)
\( L \) Length of the test section \( (m) \)
\( F \) Friction factor Dimensionless
\( u \) Mean velocity of the fluid \( (m/s) \)
\( U_i \) Overall heat transfer coefficient based on inner surface area \( (W/m^2.K) \)
\( D_i \) Internal diameter of the pipe \( (m) \)
\( A_i \) Inner surface area of test section \( (m^3) \)
\( T_1 \) Inlet temperature of hot fluid \( (K) \)
\( T_2 \) Outlet temperature of hot fluid \( (K) \)
\( T_3 \) Inlet temperature of cold fluid \( (K) \)
\( T_4 \) Outlet temperatures of cold fluid \( (K) \)
\( \Delta T_{lm} \) Logarithmic Mean Temperature Difference \( (K) \)
\( C_p \) Specific heat of the fluid \( J/Kg. K \)
\( \mu \) Dynamic Viscosity \( Pa.s \)
\( \rho \) Density \( kg/m^3 \)
\( R_e \) Reynolds Number Dimensionless
\( F \) Friction factor Dimensionless
\( \phi \) Volume fraction of nanoparticles Dimensionless
\( \phi_v \) Volume fraction percentage Dimensionless
\( \phi_m \) Mass concentration percentage Dimensionless
\( \mu_w \) Dynamic viscosity of water Dimensionless

Subscripts

\( f \) fluid
\( nf \) Nanofluid
Thermal conductivity is affected by the parameters like thermal conductivity of nanofluids at different conditions. Conductivity of Nano fluid of this type of parameters will increase the thermal shape, size, clustering, collision, porous layer, melting and pressure drop is obtained by inserting coil wires. Concentration were prepared by using two step method. An Al2O3 / water nanofluid at 0.4% and 0.8% particle volume concentration were prepared by using two step method. An Al2O3 / water nanofluid at 0.4% and 0.8% particle volume concentration were prepared by using two step method.

In the present work, an experimental study is conducted to determine the effect of different concentrations of Al2O3, CuO and Fe2O3 nanoparticles mixed in pure water as base fluid on heat transfer characteristics of double pipe counter flow heat exchanger. Yimin Xuan and Qiang Li [1] presented a procedure for preparing a nanofluid which is a suspension consisting of nanophase powders and a base liquid. Kirubadurai et.al [2] showed varying factors affecting the thermal conductivity of nanofluids at different conditions. Thermal conductivity is affected by the parameters like shape, size, clustering, collision, porous layer, melting point of nanoparticle. They mentioned that the controlling of this type of parameters will increase the thermal conductivity of Nano fluid.

An extensive experimental study has been carried out to investigate the heat transfer and pressure drop characteristics of CuO/Base oil nanofluid laminar flow in a smooth tube with different wire coil inserts under constant heat flux by Mohammad Saeedinia et.al. [3]. The effect of different parameters such as Reynolds number, wire diameter, coil pitch, nanofluid particles concentration and heat flux on heat transfer and friction factor are studied. The experimental results clearly indicate that for a specific nanoparticle concentration, increase in both heat transfer and pressure drop is obtained by inserting coil wires.

Mukeshkumar et.al. [4] studied the heat transfer coefficients of shell and helically coiled tube heat exchanger using Al2O3 / water nanofluid. This study was done by changing the parallel flow configuration into counter flow configuration under laminar flow regime. The Al2O3 / water nanofluid at 0.4% and 0.8% particle volume concentration were prepared by using two step method. An experimental study on the forced convective heat transfer and flow characteristics of a nanofluid consisting of water and different volume concentrations of Al2O3 nanofluid from 0.3% to 2% flowing in a horizontal shell and tube heat exchanger counter flow under turbulent flow conditions are investigated by Jaafar Albadr et.al. [5].

Reza Aghayari et.al. [6] Investigated the enhancement of heat transfer coefficient and Nusselt number of a nanofluid containing nanoparticles (γ-Al2O3) with a particle size of 20nm and volume fraction of 0.1%-0.3% (V/V). Effects of temperature and concentration of nanoparticles on Nusselt number changes and heat transfer coefficient in a double pipe heat exchanger with counter turbulent flow are investigated. Comparison of experimental results with valid theoretical data based on semi empirical equations shows an acceptable agreement.

CFD simulation of the heat transfer and pressure drop characteristics of nanofluids in a mini channel flow has been explained. Different nanofluids with nanoparticles of Al2O3, CuO, SiO2, and TiO2 have been used in the simulation process. A comparison of the experimental and computational results has been made for the heat transfer and pressure drop characteristics for the case of Al2O3-water nanofluid for the laminar flow by Arjumand Adil et.al. [7].

Navid Bozorgan et.al. [8] studied the effects of the automotive speed and Reynolds number of the nanofluid in different volume concentrations on the radiator performance. The results show that for CuO-water nanofluid at 2% volume concentration circulating through the flat tubes with Reynolds number 6000 when the automotive speed is 70 km/hr, the overall heat transfer coefficient and pumping power are approximately 10% and 23.8% more than that of base fluid for given conditions. Lee et.al. [9] produced oxide nanofluids. Their thermal conductivities were measured by a transient hot-wire method. The experimental results show that these nanofluids, containing a small amount of nanoparticles, have substantially higher thermal conductivities than the same liquids without nanoparticles. Comparisons between experiments and the Hamilton and Crosser model show that the model can predict the thermal conductivity of nanofluids, containing large agglomerated Al2O3 particles.

Experiments are undertaken by Azmi et.al. [10] to determine heat transfer coefficients and friction factor of TiO2/water nanofluid up to 3.0% volume concentration at an average temperature of 30°C. The investigations are undertaken in the Reynolds number range of 8000 to 30,000 for flow in tubes and with tapes of different twist ratios. A significant enhancement of 23.2% in the heat transfer coefficients is observed at 1.0% concentration. Experimental determination of heat transfer coefficients of SiO2/water and TiO2/water nanofluid up to 3% volume concentration flowing in a circular tube is undertaken by Azmi et.al.[11]. Investigations are conducted in the Reynolds number range of 5000 to 25000 at a bulk

I. INTRODUCTION

A nanofluid is a mixture of nano sized particles and a base fluid. Nanoparticles are made aluminum oxide, copper oxide and iron oxide. The base fluids used in this work is distilled water. The influence of nanofluid to increase the heat transfer rate in almost all type of heat exchangers is experimentally evaluated recently. The heat transfer augmentation using nanoparticles mainly depends on type and nanoparticle size and concentration in the base fluid.

In the present work, an experimental study is conducted to determine the effect of different concentrations of Al2O3, CuO and Fe2O3 nanoparticles mixed in pure water as base fluid on heat transfer characteristics of double pipe counter flow heat exchanger.

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temperature of 30°C. The experiments are undertaken for flow in a circular tube with twisted tapes of different twist ratios in the range of 5 ≤ H/D ≤ 93.

Exhaustive review of the suspended nanoparticles in conventional fluids, called nanofluids, has been studied by several researchers. These studies have been compiled by Sarit Kumar Das et.al.[12]. This article presents an exhaustive review of these studies and suggests a direction for future developments. Ji-Hwan Lee et.al.[13] showed that the viscosity of the Al2O3–water nanofluids significantly decreases with increasing temperature. Furthermore, the measured viscosities of the Al2O3–water nanofluids show a nonlinear relation with the concentration even in the low volume concentration (0.01%–0.3%) range, while the Einstein viscosity model clearly predicts a linear relation, and exceed the Einstein model predictions.

II. NANOFLUIDS PREPARATION

Nanoparticles are defined as particulate dispersions or solid particles with a size in the range of 10-100 nm. These materials begin to exhibit distinct properties that affect biological, chemical, and physical behaviors. A wide variety of nanoparticles exists with organic or inorganic composition, most being metals. Large variety of combinations of nanoparticles and heat transfer fluids can be used to synthesize stable nanofluids with improved thermal transport properties. Nanoparticles made from metals, oxides, carbides and carbon nanotubes can be dispersed into heat transfer fluids, such as water, ethylene glycol, hydrocarbons and fluorocarbons with or without the presence of stabilizing agents

For research purpose, alumina (alpha-Al2O3), Fe2O3, and CuO nanoparticles are used for preparation of nanofluids. Pure water is used as base fluid. Work is done on four mass fractions of all types of nanoparticles such as 0.5%, 1%, 1.5% and 2%.

The physical characteristics of alumina (Al2O3) are APS: 15±5 nm, with Purity: 99.99%, SSA: 17.8m2/gm with Alpha-Phase Crystal Structure. Iron oxide (Fe2O3) physical and thermal characteristics are: APS: 30-50 nm, Purity: 99%, SSA: 20-60m2/gm with spherical (alpha phase Fe2O3) Crystal Structure. The Density of these Particles are 5.25 gm/cm² and Specific heat of Nano Particles is 780 J/kg.k

Copper oxide (CuO) commonly referred to Black crystalline powder that is found as balls or lumps of various mesh sizes, possesses strong ionic inter-atomic bonding giving rise to its desirable material characteristics. Copper Oxide is most cost effective and one of the most versatile of refractory ceramic oxides. The physical characteristics of Copper Oxide nanoparticles used in the present study are APS: 30-50 nm, Purity: 99 %, Color: Black with Spherical Crystal Structure.

2.1 Surfactants

Surfactants are the substances that increase the solubility of nanoparticles into a base fluid by decreasing the surface tension of base fluid. These are also called as dispersants since they get attached to the solute particles (cohesion) and thereby increase the repulsion force between the nanoparticles. This repulsion prevents the nanoparticles from clustering and hence produces a homogenous and stable solution called nanofluid.

A suitable surfactant must be selected upon the type of base fluid and nanoparticles. For the present study, three surfactants are taken to select the best suitability for bulk preparation of nanofluid which are shown in figure 1. These are C-Tab, Twin-80, and Span-80.

Figure 1: Photograph of Samples of Surfactants

For all the three types of nanoparticles, samples have been prepared and tested with the help of Magnetic Stirrer. Pictorial view of magnetic stirrer is shown in figure 2.
III. THERMOPHYSICAL PROPERTIES OF NANOFLOUIDS

Thermal and physical properties of nanofluids are different from base fluid and will change with mass concentration percentage of nano materials. It is assumed that the influence of surfactant on the thermal and physical properties is neglected. Several researchers have done several experiments and presented the mathematical formulations to evaluate the properties. Most of the relations have been taken from the reference [14] and the reference [15].

The specific heat of nanofluids for various nano particle mass concentrations is estimated by using the equation [14].

\[ C_{p, nf} = C_{p, np} \phi + (1 - \phi) C_{p, bf} \]  

Volume concentration was determined from the specified mass concentration at the dispersed fluid by the following equation [14] as shown below:

\[ \phi_v = \frac{1}{\frac{(\rho_{np})}{(\rho_{bf})} + 1} \times 100(\%) \]  

Once the volume concentration is determined, the density of the dispersed nanofluid can be determined from relation [14] as:

\[ \rho_{nf} = (1 + \phi_v)\rho_{bf} + \phi_v\rho_{np} \]  

Viscosity of the nanofluid can be calculated by using Einstein’s classical equation [19] as shown below:

\[ \mu_{nf} = (1 + 2.5 \phi_v)\mu_w \]  

Where, \( \mu_w \) is the dynamic viscosity of water

Reynolds Number (Re) for any flowing fluid can be calculated by using standard formula as:

\[ Re = \frac{u \rho_n}{\mu} \]  

Average velocity (u) can be calculated by the relation:

\[ u = \frac{m}{\rho A_1} \]  

IV. EXPERIMENTATION

Main objective of the project is to see that the heat transfer augmentation with respect to pressure drop at a particular flow rate and temperature. Counter flow heat exchanger is used to measure the heat transfer coefficient. It consists of concentric tube Heat Exchanger, Instant Water Heater and Water cooler, submerged pump, Thermocouples, Rotameters, Pressure gauges, Regulating valves.

A photograph of experimental set up of counter flow heat exchanger is shown in Fig.3. Control valves are used to regulate the flow rate of both hot and cold fluids flowing through the concentric tubes. The concentric tube is applied with a layer of asbestos insulation to minimize any heat losses from outer surface of outer pipe.
V. RESULTS AND DISCUSSION

Experiments have been carried out in counter flow heat exchanger with pure water and also with different nanoparticles mass concentrations called nanofluids. We have investigated how overall heat transfer coefficient is varying with Reynolds number.

Figure 3: A view of experimental setup

Figure 4.1 represents the increase of pressure drop with different percentages of nanoparticle mass concentration in the base fluid. When the experiment is done with pure water at a particular flow rate, the pressure drop is observed approximately 3.2kPa. When the water is added with Alumina, copper oxide and iron oxide nanoparticles, the pressure drop for all the three fluids are different.

Figure 4 gives the information about the increase of overall heat transfer coefficient with change in nanoparticle mass concentration percentage. It is observed from the graphs that the increase of overall heat transfer coefficient is more for Fe₂O₃ than CuO and Al₂O₃ is in between. The increment of $U_i$ is nearing to linear with mass concentration. The pressure drop also increasing with increasing in heat transfer coefficient. It is observed that the increase of pressure drop is less when compared with the increase of heat transfer coefficient ($U_i$).
Figure 5: Variation of Heat transfer coefficient with Reynolds number at 0.5% mass concentration

Figure 6: Variation of Heat transfer coefficient with Reynolds number at 1% mass concentration

Figure 7: Variation of Heat transfer coefficient with Reynolds number at 1.5% mass concentration
Variation of overall heat transfer coefficient with flow rate is presented in the figures 5 to figures 8. It is observed from the graphs that the increase of heat transfer coefficient with increase of flow rate is asymptotic. The reason for this behavior may be due to more disturbances within the fluid as the flow rate is increased. Due to more turbulence within the fluid, the heat carrying capacity will increase and hence, the heat transfer rate is more. Heat transfer carrying capacity is more in case of more percentage mass concentrated nanofluid. It is also seen that the more heat transfer rate with increase of mass fraction percentage of nanofluids.

As a part of nanofluid properties, the experiments are conducted know how the dynamic viscosity is varying with temperature. The viscosity generally plays a major role in estimating the pumping power. Most of the heat exchange equipment works above room temperatures, particularly heat carrying fluid.

VI. CONCLUSIONS

Nanofluids are prepared by two-step process i.e. dispersing the nanoparticles into base fluids. A custom built stirrer is used to disperse the particles properly and to minimize particle agglomeration to get a uniform stable suspension. C-Tab is used for Al$_2$O$_3$ & Fe$_2$O$_3$ as a surfactant, to maintain stability and proper dispersion. The, Tween 80 is used as surfactant for CuO.

All the three nanoparticles are used for preparing the nanofluids with distilled water as a base fluid. These are prepared with the help of surfactants with nanoparticles mass percentage of 0.5 %, 1.0%, 1.5% and 2.0%.

As an example, when we changed the mass concentration percentage of Al$_2$O$_3$ from 0.5% to 2% in the base fluid, the heat transfer coefficient increased from 106% to 276.79% at a particular flow rate and input conditions. Whereas the Pressure drop of nanofluid for same conditions, the maximum increase is approximately 50% for 0.5% mass concentration. The increment of pressure drop with increase of percentage mass concentration is not as drastic as heat transfer coefficient.

It has been observed that with increase in flow rate, and particle concentration, the heat transfer coefficient is increasing better for Fe$_2$O$_3$ than the other two nanofluids at all four concentrations.

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