EXPERIMENTAL STUDY ON HEAT TRANSFER ENHANCEMENT BY USING WATER – ALUMINA NANOFLUID IN A HEAT EXCHANGER

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ABSTRACT

In this paper an experimental study on the forced convective heat transfer and flow characteristics of alumina nanofluid consisting of water and different volume concentrations of Al_2O_3 nanofluid (0.1–3) % flowing in a horizontal double tube counter flow heat exchanger under turbulent flow conditions are investigated. Effects of temperature and concentration of nanoparticles on Reynolds number and heat transfer coefficient in a heat exchanger with counter turbulent flow are investigated. Experimental results show a considerable increase in heat transfer coefficient and Reynolds number. The results show that the convective heat transfer coefficient of nanofluid is slightly higher than that of the base liquid at same mass flow rate and at same inlet temperature. The heat transfer coefficient of the nanofluid increases with an increase in the mass flow rate, also the heat transfer coefficient increases with the increase of the volume concentration of the Al_2O_3 nanofluid.

Keywords - Nanofluids; Al_2O_3 Nanofluid; Heat Transfer Coefficient; Heat Transfer Applications; Heat Exchanger

I. INTRODUCTION

Heat exchanger is a device which is used to transfer the heat from one fluid to another fluid. It is widely used in several industries such as power plants, air conditioning equipments, Automobile, chemical processing plant. Due to the important role that heat exchanging equipment plays in different industries, it is very important to maximize their efficiency in order to conserve energy. One way, to achieve this goal, is the use of nanofluids instead of traditional coolants such as water, ethylene glycol and cooling oils. This method has been the subject of much attention in recent years and many studies have been conducted to determine the benefits and heat transfer characteristics of nanofluids. Nanofluids are made by dispersing nano-sized particles in base fluids such as water, ethylene glycol and oils. Choi [1] was the first person to do so and he named the resulting solution “nanofluid”. A decade ago, with the rapid development of modern nanotechnology, particles of nanometer-size (normally less than100 nm) are used instead of micrometer-size for dispersing in base liquids, and they are called nanofluids. Many researchers have investigated the heat transfer performance and flow characteristics of various nanofluids with different nanoparticles and base fluid materials. Several following existing published articles which associate with the use of nanofluids are described in the following sections. Abu-Nada, et al. [2] used an efficient finite-volume method to study the heat transfer characteristics of natural convection for CuO/EG/water nanofluid in a differentially heated enclosure. His results show that the dynamic viscosity and friction factor increased due to dispersing the alumina nanoparticles in water. Chein and Chuang [3] reported experimentally on micro channel heat sink (MCHS) performance using CuO–water nanofluids as coolants. The results showed that the presence of nanoparticles creates greater energy absorption than pure water at a low flow rate and that there is no contribution from heat absorption when the flow rate is high. Khwanchit Wongcharee & Smith Eiamsa-ard [4] carried out the study on heat transfer enhancement by using CuO/water nanofluid in corrugated tube equipped with twisted tape. The experimental results reveal that at similar operating conditions, heat transfer rate, friction factor as well as thermal performance factor associated with the simultaneous application of CuO/water nanofluid and twisted tape are higher than those associated with the individual techniques. Reza Aghayari et al. [5] carried out investigation on the enhancement of heat transfer coefficient and Nusselt number of a nanofluid containing nanoparticles (γ-AL_2O_3) with a particle size of 20nm and volume fraction of 0.1%–0.3% (V/V). Experimental results shown that the considerable increases in heat transfer coefficient and Nusselt number up to 19%–24%, respectively. Also, it has been observed that the heat transfer coefficient increases with the operating temperature and concentration of nanoparticles. Jaafar Albadr et al. [6] carried out an experimental study on the forced convective heat transfer and flow characteristics of a nanofluid consisting of water and different volume concentrations of Al_2O_3 nanofluid (0.3–2)% flowing in a horizontal shell and tube heat exchanger counter flow under turbulent flow conditions . It is observed from the results that the convective heat transfer coefficient of nanofluid is slightly higher than that of the base liquid at same mass flow rate and at same inlet temperature. The heat transfer coefficient of the nanofluid increases with an increase in the mass flow rate, also the heat transfer coefficient increases with the increase of the volume concentration of the Al_2O_3 nanofluid, however increasing the volume concentration cause increase in the viscosity of the nanofluid leading to increase in friction factor. Zan Wu et al. [7] has carried out experimental investigation on the pressure drop and convective heat transfer characteristics of water and five alumina/water nanofluids of weight concentrations from 0.78% wt. to 7.04% wt. for both laminar flow and turbulent flow inside a double-pipe helically coiled heat exchanger. For both laminar flow and turbulent flow, no anomalous heat transfer enhancement was found. The heat transfer enhancement of the five nanofluids over tap water ranges from 0.37% to 3.43% for the constant flow velocity basis for both laminar and turbulent flows. E. Esmaeilzadeh et al. [8] conducted experimental study to investigate heat transfer and friction factor characteristics of g- Al_2O_3/water nanofluid through circular tube with twisted tape inserts with various thicknesses at constant heat flux. In this work, g-Al_2O_3/water nanofluids with two volume concentrations of 0.5% and 1% were used as the working fluid. Results showed that nanofluids have better heat transfer performance when utilized with thicker twisted tapes. At the same time, the increase in twisted tape thickness leads to an increase in friction factor. In the end, the combined results of these two phenomena result in enhanced convective heat transfer coefficient and thermal performance. Tun-Ping Teng et al. [9] in this study analyzed the characteristics of alumina (Al_2O_3)/water nanofluid to determine the feasibility of its application in an air-cooled heat exchanger for heat dissipation for PEMFC or electronic chip cooling. It is observed that the nanofluid has a higher heat exchange capacity than water, and a higher concentration of nanoparticles provides an even better ratio of the heat exchange. The cross-section aspect ratio of tube in the heat exchanger is another important factor to be taken into consideration. Asirvatham et al. [10] in this experimental study of steady state convective heat transfer of de-ionized water with a low volume fraction (0.003% by volume) of copper oxide (CuO) nanoparticles dispersed to form a nanofluid that flows through a copper tube. The results have shown 8% enhancement of the convective heat transfer coefficient of the nanofluid even with a low volume concentration of CuO nanoparticles. The heat transfer enhancement was increased considerably as the Reynolds number increased. Yones and Ahmad [11] in this research evaluated improved rate of heat transfer coefficient and friction factor of Cu-O water nanofluid compared to water-based fluids by Cu-O water nanofluid as an incompressible, homogeneous and turbulent flow in the shell and tube heat exchangers. Increase in the volume concentration and Reynolds of nanofluid increase the local heat transfer coefficient, overall heat transfer coefficient and pressure drop of nanofluids. Improved heat transfer coefficient compared to water-based fluids is concluded as 32 percent. Rohit et al. [12] in this paper concentrated on an experimental study on concentric tube heat exchanger for water to nanofluids heat transfer with various concentrations of nanoparticles in to base fluids and application of nanofluids as working fluid. The experimental results on this type of heat exchanger configuration and water nanofluids could not be located in literature. Overall heat transfer coefficient was experimentally determined for a fixed heat transfer surface area with different volume fraction of nanoparticles in to base fluids and results were compared with pure water. It observed that, 3 % nanofluids shown optimum performance with overall heat transfer coefficient 16% higher than water. Li and Xuan [13] have built an experimental system to investigate convective heat transfer and flow characteristics of the nanofluid in a tube. The experimental results shown that the suspended nanoparticles remarkably increase the convective heat transfer coefficient of the base fluid and it is seen that the friction factor of the sample nanofluid with the low volume fraction of nanoparticles is almost not changed. Compared with the base fluid, for example, the convective heat transfer coefficient is increased about 60% for the nanofluid with 2.0 vol% Cu nanoparticles at the same Reynolds number. Yarmand et al. [14] carried out numerical investigation to find out the thermal characteristics of turbulent nanofluid flow in a rectangular pipe. The numerical results indicate that SiO_2-water has the highest Nusselt number compared to other nanofluids while it has the lowest heat transfer coefficient due to low thermal conductivity. The Nusselt number increases with the increase of the Reynolds number and the volume fraction of nanoparticles. The results of simulation have shown a good agreement with the existing experimental correlations.

II. EXPERIMENTAL SET UP

The experimental set up as shown in the figure 1 could be used to transfer heat from nanofluid in a heat exchanger to water stored in a separate tank and make temperature calibrations for the same by employing two thermocouples. Also, Rotameter are installed in the pipes carrying nanofluid and water to check respective flowing rates. The complete system will be very dynamic and easy to use. It consists of two flow loops, a heating unit to heat the nanofluid and temperature measurement system. The two flow loops carries heated nanofluid and the other cooling water. Each flow loop includes a pump with a Rotameter, a reservoir and a bypass valve to maintain the required flow rate. Thermocouples are inserted on the heat exchanger to measure the bulk temperatures of inlet and outlet fluid streams. The pumps are used with maximum delivery rate of 800 LPH.

2.1 NanoFluid Preparation

In this present work nanofluid is prepared from the two step method. Alumina particles (α- Al2O3) are purchased from the commercial source with average particle size 20-30nm. Nanofluid samples are prepared with four different nanofluid concentrations that are 0.3%, 0.2%, 0.15% and 0.1% by volume fraction.

Figure 1. Experimntal Set Up

III. DATA PROCESSING

To calculate the overall heat transfer coefficient and convective heat transfer rate of nanofluid different formulas are used. The nanofluid density can be calculated by using the Pak & Cho [15] and Xuan [16] correlations, which is defined as given below:

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

$$c_{p,nf} = \frac{(1-\phi)\,\rho_{bf}c_{p,bf} + \phi\rho_p c_{p,p}}{\rho_{nf}}$$

Where, Φ is nanoparticle volume concentration and ρ_p, ρ_{bf} and $c_{p,p}$, $c_{p,bf}$ are the densities and the specific heats of the nanoparticles and base fluid, respectively.

Heat transfer can be defined as,

$$Q = m\, c_p\, \Delta T$$

Where, ΔT is the temperature difference between inlet and outlet temperature for nanofluid and water.

The overall heat transfer coefficient,

$$Q = UA_s\Delta Tm$$

Where, U is the overall heat transfer coefficient and A_s is the surface area.

IV. RESULTS AND DISCUSSION

To evaluate the accuracy of measurements, experimental system has been tested with distilled water before measuring the heat transfer characteristics of different volume concentration of Al_2O_3/water. From the experimental system, the values that have been measured are the temperatures of the inlet and outlet of the hot water as well as the inlet of the distilled water and the different concentrations of nanofluids at different mass flow rates.

4.1 The overall Heat Transfer Coefficient of the Nanofluid

Figure 2-5 shows the overall heat transfer coefficient of aluminum oxide nanofluid and water in terms of the Reynolds number at different volume concentrations. The results show the increase of the overall heat transfer coefficient with the Reynolds number and temperature of the nanofluid. Compared to the base fluid, the overall heat transfer coefficient of aluminum oxide nanofluid increases with the increase in concentration at a fixed Reynolds number.

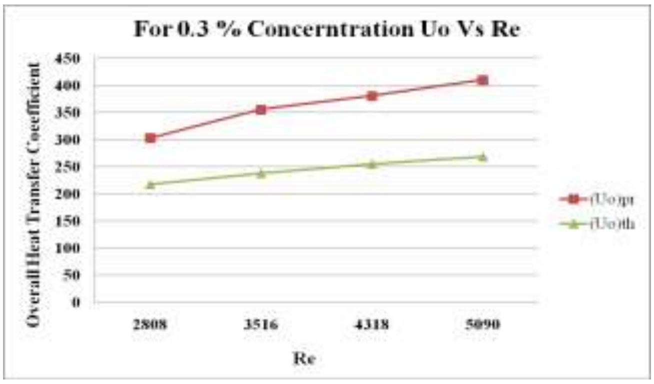

Figure 2. Overall Heat Transfer Coefficient of Al_2O_3/Water Nanofluid Versus Reynolds Number for Volume Concentration 0.3

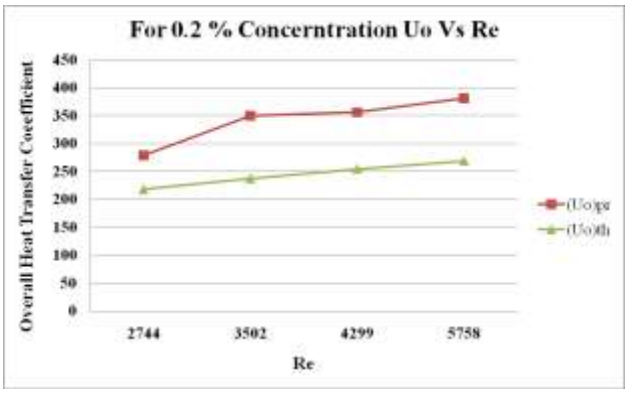

Figure 3. Overall Heat Transfer Coefficient of Al_2O_3/Water Nanofluid Versus Reynolds Number for Volume Concentration 0.2

The overall heat transfer coefficient is found to be the highest for aluminum oxide nanofluid at the concentration of 0.3 and a Reynolds number of about 5090, compared to the base fluid. The overall heat transfer coefficient is lowest for volume concentration 0.1 of aluminum oxide nanofluid.

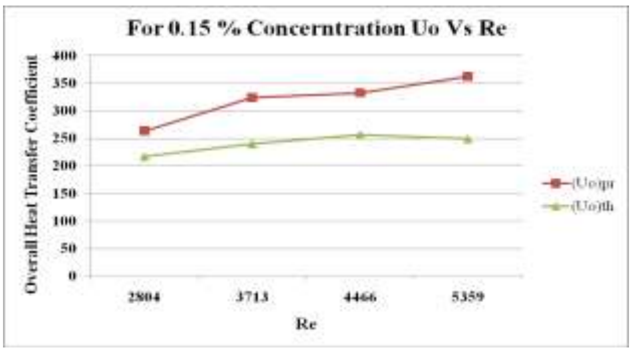

Figure 4. Overall Heat Transfer Coefficient of Al_2O_3/Water Nanofluid Versus Reynolds Number for Volume Concentration 0.15

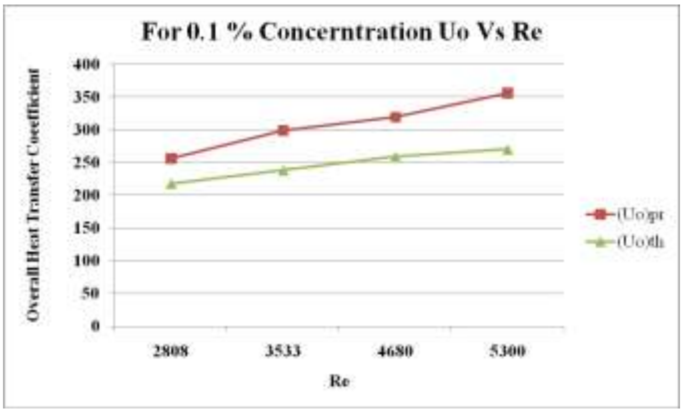

Figure 5. Overall Heat Transfer Coefficient of Al_2O_3/Water Nanofluid Versus Reynolds Number for Volume Concentration 0.1

4.2 Convective Heat Transfer Coefficient of the Nanofluid

The graphs of the convective heat transfer coefficient versus Reynolds number at different volume concentrations is shown in Figure 6-9. The result shows the increase of the convective heat transfer coefficient with the Reynolds number and temperature of the nanofluid. Compared to the base fluid, the convective heat transfer coefficient of aluminum oxide nanofluid increases with the increase of concentration in a fixed Reynolds number. The overall heat transfer coefficient is found to be the highest for aluminum oxide nanofluid at the concentration of 0.3 and a Reynolds number of about 5090, increasing up to compared to the base fluid. The possible reasons for this increase may be as follows:

(1) A nanofluid with suspended nanoparticles which increases the thermal conductivity of the mixture,

(2) High energy exchange process, which is resulted from the amorphous movement of the nanoparticles.

Experimental results indicate that the effects of the nanoparticles on the thermal conductivity increase with the temperature. It is assumed that the main mechanism for the thermal conductivity of the nanofluid is the random motion of the nanoparticles.

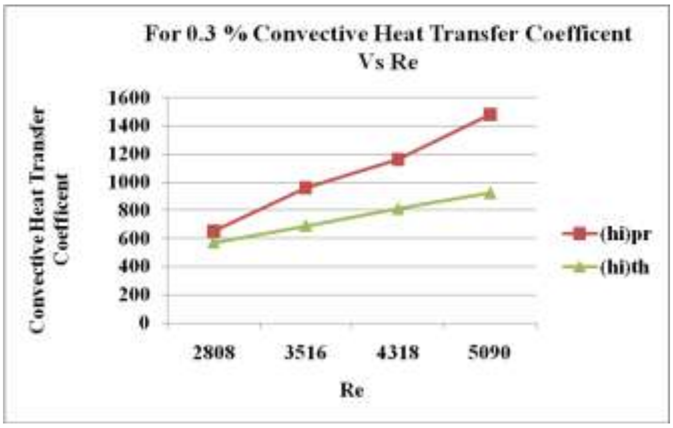

Figure 6. Convective Heat Transfer Coefficient of Al_2O_3/Water Nanofluid Versus Reynolds Number for Volume Concentration 0.3.

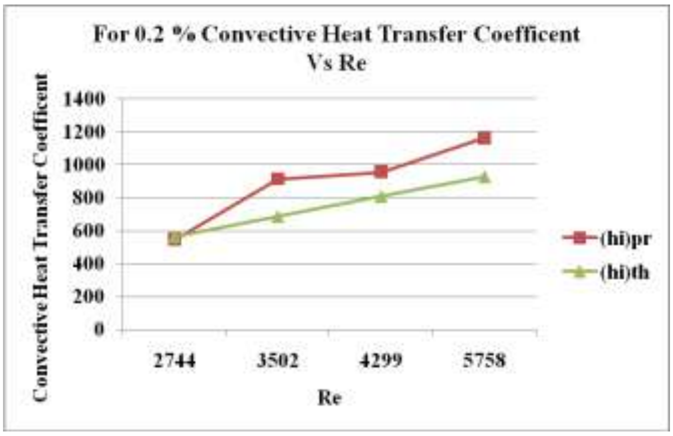

Figure.7 Convective Heat Transfer Coefficient of Al_2O_3/Water Nanofluid Versus Reynolds Number for Volume Concentration 0.2

Thus, the increase in the thermal conductivity is higher for smaller particles than for larger particles at the high temperatures. This results in the increase of heat transfer efficiency caused by the increase of thermal conductivity, convective heat transfer, and the thinness of thermal boundary layer. This increase can be attributed to the thermal conductivity. The increase in the thermal conductivity can increase the heat transfer coefficient in the thermal boundary layer near the tube wall.

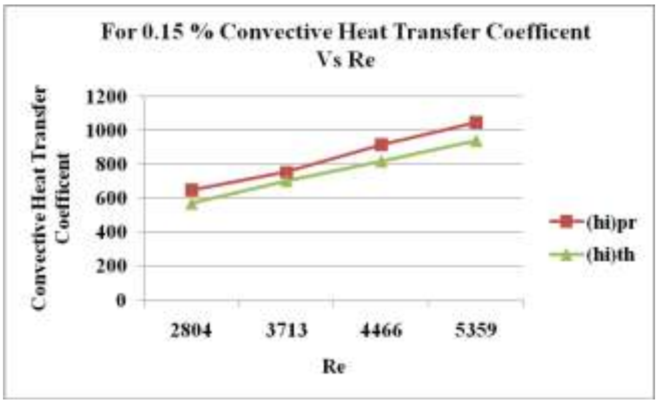

Figure.8 Convective Heat Transfer Coefficient of Al_2O_3/Water Nanofluid Versus Reynolds Number for Volume Concentration 0.15.

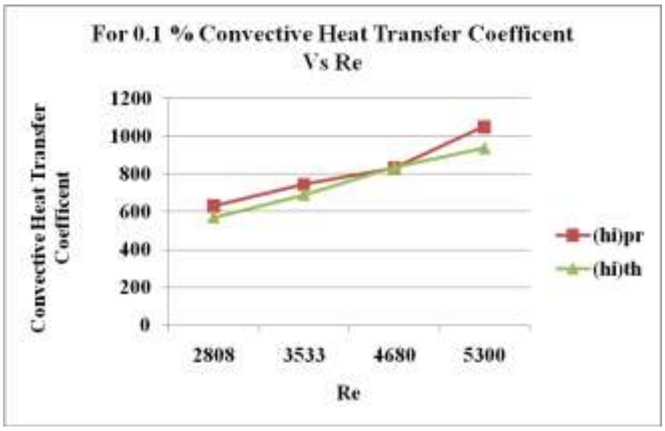

Figure.9 Convective Heat Transfer Coefficient of Al_2O_3/Water Nanofluid Versus Reynolds Number for Volume Concentration 0.1.

V. CONCLUSION

The convective heat transfer performance and flow characteristics of Al_2O_3 nanofluid flowing in a double tube heat exchanger have been experimentally investigated. Experiments have been carried out under turbulent conditions. The effect of particle concentration and the Reynolds number on the heat transfer performance and flow behavior of the nanofluid has been determined. Attention has been focused on the improvement of heat exchanger efficiency by adding solid particles to heat transfer fluids. Many researchers have investigated the effect of nanoparticles on different process parameters like hydrodynamic and Thermophysical properties. However, researches were seldom performed to evaluate the effect of turbulent nanofluid flow on heat transfer. This study investigated the heat transfer enhancement of the nanofluid containing aluminum oxide nanoparticles and water under the condition of turbulent flow in a double pipe heat exchanger. The heat transfer values were measured in the turbulent flow of a nanofluid of average particle size of 20-30nm aluminum oxide suspended particles with the volume concentration of 0.1–0.3% (V/V) in water. Experimental results show the increase of the overall heat transfer coefficient and convective heat transfer coefficient in the turbulent flow regime with the addition of the nanoparticles to the fluid. The obtained results are in agreement with the results from the literature. This increase in the heat transfer coefficient may be due to the high density of nanoparticles on the wall pipe and the migration of the particles.

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