Asian Journal of Chemistry; Vol. 24, No. 6 (2012), 2589-2592

ASIAN JOURNAL OF CHEMISTRY

www.asianjournalofchemistry.co.in

Experimental Investigation of Convective Heat Transfer of Nanofluids in a U-Type Heat Exchanger

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(*Received*: 25 May 2011; *Accepted*: 13 January 2012) AJC-10951

Nanofluids are a class of heat transfer fluids created by dispersing solid nanoparticles in traditional heat transfer fluids. This study describes an experimental design and a numerical method to demonstrate the forced convective heat transfer using traditional fluid and zinc oxide/water (0.5 % v/v) nanofluid in a U-type double-pipe heat exchanger utilizing commercially available equipment. Experiments were conducted to determine the actual heat transfer rates and overall heat transfer coefficients under operational conditions using nanofluid and the heat transfer enhancement determined compared to fluids without nanoparticles. The experimental results show that the heat transfer rate and heat transfer coefficients of the nanofluid is higher than that of the base liquid (*i.e.*, water). For a given hot fluid flow rate, the increase in the overall heat transfer coefficient is more forcible at high cold flow rate. The heat transfer rate and heat transfer coefficients increases with increase in mass flow rates of hot and cold streams.

Key Words: Convective heat transfer, U-type heat exchanger, Nanofluid.

INTRODUCTION

Heat exchangers are a device that exchanges the heat between two fluids of different temperatures that are separated by a solid wall. In a heat exchanger forced convection allows for the transfer of heat of one moving stream to another moving stream. With convection as heat is transferred through the pipe wall it is mixed into the stream and the flow of the stream removes the transferred heat. This maintains a temperature gradient between the two fluids. Double-pipe heat exchanger is made of concentric inner and outer pipe. Cold and hot liquid respectively flows in the gap of inner pipe and sleeve pipe and changes heat at the same time. Inner pipe is used U tube to connect. Sleeve pipe is used direct pipe to connect at both ends. Structure of double pipe heat exchanger is simple and heat transmission is large. It's easy to clean a heat exchanger to disassemble and assemble. Flow rate is appropriate and it is possible to have a backwash. Flow rate of exchanging heat is high. It's conformed to GMP demand of medicine industry, cooling (heat exchanging) demand of food industry, *etc.*[1,2]. The double pipe heat exchangers can be used in parallel or series configurations as shown in Fig. 1.

To enhance the thermal efficiency of the heat exchangers, the thermal capability of the working fluid must be increase[3,4]. A novel approach to engineering fluids with better heat transfer properties is based on the rapidly emerging field of nanotechnology. The use of particles of nanometre dimensions first materialized in a series of studies conducted at the Aargonne National Laboratory. Choi[5] was probably the first to call the fluids with suspended particles of nanometer dimensions nanofluids, which has gained popularity. Addition of small amount of high thermal conductivity solid nanoparticles in base fluid increases the thermal conductivity, thus increasing the heat transfer rate in the heat exchangers[6,7].

Fig. 1. Double pipe heat exchangers in series configuration

Nanofluid is the name conceived by Argonne National Laboratory to describe a fluid in which nanometer-sized particles are suspended. Nanofluids are a class of heat transfer fluids created by dispersing solid nanoparticles in traditional heat transfer fluids. The results show that nanofluids have thermal properties that are very different from those of conventional heat transfer fluids such as water or ethylene glycol.

The Argonne National Laboratory performed nanofluid experiment, where it was found there was a 20 % increase in the thermal conductivity. Theoretically the thermal conductivity increases are based on the volume fraction and shape of the particles. The increase of the thermal conductivity leads to an increase in heat transfer performance. In fact the reduction of the thermal boundary layer thickness due to the presence of the nanoparticles and the random motion within the base fluid may have important contributions to such heat transfer improvement as well[8,9]. Fundamental research on the heat convection of nanofluid discuss the effects of particle size, flow condition, cross-section shape, theoretical models, *etc*., in theoretical and experimental studies, obtaining many achievements[8-13]. Research on the application of nanofluid to actual component or system also presents some interesting results. Tsai *et al.*[10] investigated gold-deionized water nanofluid flowing in a conventional heat pipe with a diameter of 6 mm and a length of 170 mm. Gold nanoparticles of 2-35 nm and 15-75 nm in size were used in this study.

Yang *et al.*[11] reported an experiment which studied the convective heat transfer coefficient of graphite nanoparticles dispersed in liquid for laminar flow in a horizontal tube heat exchanger. Disc-shaped nanoparticles of different sources (aspect ratio (l/d) of about 0.02) were used in this study. The experimental results showed that the heat transfer coefficient increased with the Reynolds number as well as the particle volume fraction. Nguyen *et al.*[12] applied Al_2O_3 nanofluid to an electronic liquid cooling system. When the volume fraction was 6.8 vol. %, the convective heat transfer coefficient was enhanced by 40 % maximum. They used particles of two different sizes: 36 and 47 nm. Their experimental results indicate that under the same volume fraction, smaller particles seem to have a higher heat transfer coefficient.

Lee *et al.*[13] investigated experimentally for the suspension of 4 % volume 35 nm CuO particles in ethylene glycol and observed 20 % increase in thermal conductivity. Xuan and Li[14] have studied 35 nm Cu/deionized water nanofluid flowing in a tube with constant wall heat flux and showed that the ratio of the Nusselt number for the nanofluid to that of pure water under the same flow rate, varies from 1.05 to 1.14 by increasing the volume fraction of nanoparticles from 0.5 to 1.2 %, respectively

Wen and Ding[15] presented an experimental study, which evaluated the convective heat transfer coefficient of Al_2O_3 nanoparticles suspended in deionized water for laminar flow in a copper tube, focusing in particular on the entrance region. The various concentrations of nanoparticles (0.6, 1.0 and 1.6 %) were tested under a constant wall heat flux. The results showed that the use of nanofluids affected a pronounced increase in the heat transfer coefficient causing a decrease in the thermal boundary layer thickness and will decrease along the tube length. Experimental studies of pressure drop and convective heat transfer of TiO_2/water nanofluid in a double pipe heat exchanger are reported by Duangthongsuk and Wongwises[16]. In this study effect of mass flow rate of hot and cold fluids and nanofluid temperature on heat transfer coefficient have been studied. The results show that the convective heat transfer coefficient of nanofluid is slightly higher than that of the base liquid by about 6-11 %. Heat transfer in a mini heat exchanger using CuO/water nanofluids has been investigated by Mapa and Mazhar[17]. In this study, theoretical heat transfer rates were calculated using existing relationships in the literature for conventional fluids and nanofluids. Also heat transfer enhancement determined compared to fluids without nanoparticles. At mass flow rates of 0.005 kg/s, a 5.5 % increase in heat transfer rate of 0.01 % CuO/water nanofluid is observed.

In the present work experimental works have been done for investigation of convective heat transfer of ZnO/water nanofluid in the double pipe heat exchanger. Effects of hot and cold stream velocities on heat transfer rate and heat transfer coefficients have been investigated.

EXPERIMENTAL

The experimental setup is shown in Fig. 2.

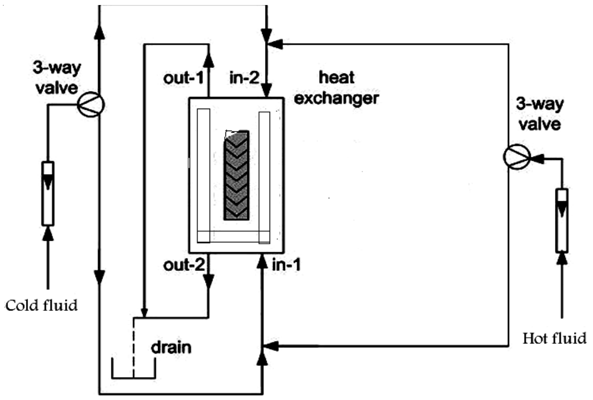

Fig. 2. Schematic diagram of the experimental unit

The calculations of heat transfer coefficients were conducted in a P.A. Hilton laboratory heat exchangers unit. The main characteristics parameters of concentric tube heat exchangers are shown in Table-1. The test fluids were distilled water and ZnO/water nanofluid.

TABLE-1
CHARACTERISTICS PARAMETERS OF CONCENTRIC TUBE HEAT EXCHANGER

Inner tube material	316 stainless steel
Outlet diameter (inner tube)	0.012 m
Wall thickness	0.001 m
Outer tube material	Clear acrylic
Inlet diameter(outer tube)	0.022 m
Active heat transfer length	2*0.318 m

The heat removed from the hot fluid, Q_h and the heat absorbed by the cooling liquid, Q_c are calculated by eqns. 9 and 10. It is confirmed that they are practically equal.

$$Q = Q_C = m_c C_{pc} (\Delta T_C) \qquad (1)$$

$$Q = Q_H = m_H C_{pH} (\Delta T_H) \qquad (2)$$

The total heat transfer coefficient is defined as:

$$U = \frac{Q}{A * LMTD} \tag{3}$$

$$LMTD = \frac{(T_{HO} - T_{Ci}) - (T_{Hi} - T_{CO})}{Ln \frac{(T_{HO} - T_{Ci})}{(T_{HI} - T_{Ci})}} \tag{4}$$

During each experiment, the flow rates of the hot and cold fluids were set and after steady state was achieved, the temperatures were recorded. Temperature data acquired using high accuracy T-type thermocouples, located at the inlet and outlet of the hot and cold streams, respectively.

Then, the mass flow rate of hot fluid was increased and new data were obtained. The aforementioned procedure was also repeated for various cold fluid flow rates. Finally the overall heat transfer coefficients and heat transfer rates can be calculated from the mentioned equations.

Nanofluid preparation: Preparation of a stabilized nanofluid is of utmost importance. Poorly prepared nanofluids will render biphasic heat transfer. Another challenge is posed by nanoparticle aggregation, which creates larger particles (in micrometer order), thus rendering the nano-related discussions senseless. In order to prepare the nanofluids by dispersing the nanoparticles in a base fluid, proper mixing and stabilization of the particles is required. The ZnO/water nanofluid used in this study was prepared by adding commercial nanoparticles to deionized water. We prepared a nanofluid with concentration of 0.5 wt. % with the average particle size of 60 nm. The nanofluid was dispersed several times by ultrasonic dispersion and an electromagnetic stirrer. The transmission electron microscope was used to monitor the dispersion of the nanoparticles in the water (Fig. 3). The figure shows that a little agglomeration was observed after 3 h.

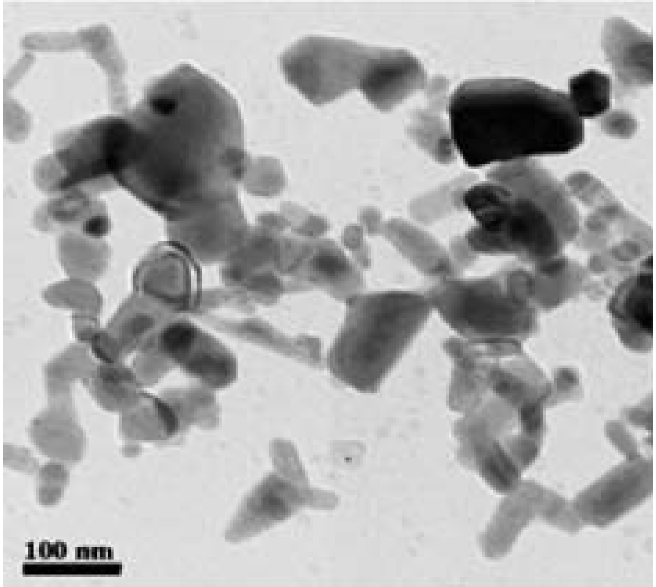

Fig. 3. TEM photograph of ZnO/water nanoparticles

According to Williams *et al.*[18], the advantages of using nanofluids depend on the relative increase of thermal conductivity, density, heat capacity and viscosity. These parameters are defined as follow:

Viscosity and density: The viscosity and density of the nanofluids can be calculated as follow:

$$\mu_{nf} = (1 + 2.5\phi)\mu_f \tag{5}$$

$$\rho_{nf} = \phi\rho_s + (1 - \phi)\rho_f \tag{6}$$

Heat capacity: The heat capacity equation presented as follow:

$$C_{P_{NF}} = \frac{\phi\rho_S C_{P_S} + (1 - \phi)\rho_f C_{P_f}}{\rho_{nf}} \tag{7}$$

Thermal conductivity: Choi[5] correlation can be used for calculation of nanofluid effective thermal conductivity as follow:

$$k_{nf} = \left[\frac{k_s + 2k_f + 2(k_s - k_f)(1+\beta)^3\phi}{k_s + 2k_f - (k_s - k_w)(1+\beta)^3\phi}\right] k_f \tag{8}$$

In this equation β is the ratio of the nanolayer thickness to the original particle radius and $\beta = 0.1$was used.

RESULTS AND DISCUSSION

Concentric tube heat exchangers are the simplest type of heat exchanger. Essentially it is a tube inside of a tube. In one part a hot fluid flows and transfers its heat through the wall of a metal (stainless steel) to another cold fluid. The counter flow configuration has been used through all of the experimental works. Nanofluid flows inside the inner tube as a hot stream while distilled water entered annular section as a cold stream. Effect of hot and cold fluids flow rates on the heat transfer rate and heat transfer coefficients of nanofluid has been studied.

Figs. 4 and 5 show that the heat transfer rate and total heat transfer coefficients versus hot fluid mass flow rate for various cold fluid flow rates. Also the comparison between the heat transfer of nanofluid and base fluid is shown in Fig. 6. It can be seen from Fig. 4 that the heat transfer rates increases with increasing in hot and cold liquid flow rates. Also for a given hot or cold flow rate, the heat transfer rate and total heat transfer coefficient of the nanofluid is higher than the distilled water. Increasing the hot fluid flow rate leads to an increase in the heat transfer rate and results in an increase in the heat transfer coefficient.

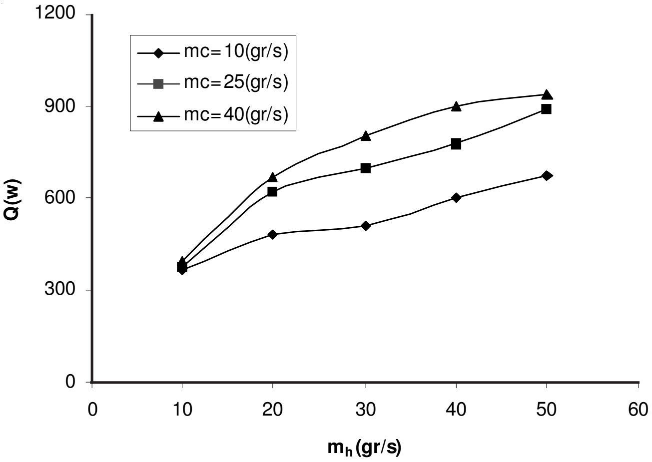

Fig. 4. Effect of hot and cold flow rate on heat transfer rate of nanofluids in double pipe heat exchanger

Also as shown in Fig. 5 for a given hot fluid flow rate; the increase in the overall heat transfer coefficient is more forcible at high cold flow rate. For example in the m_{cold} = 10 gr/s and m_{hot} = 40 gr/s the increase in U is 7.5 % but in the m_{cold} = 40 gr/s and m_{hot} = 40 gr/s, the increase is 14.1 %. This observation agrees with the results reported by Duangthongsuk and Wongwises[16].

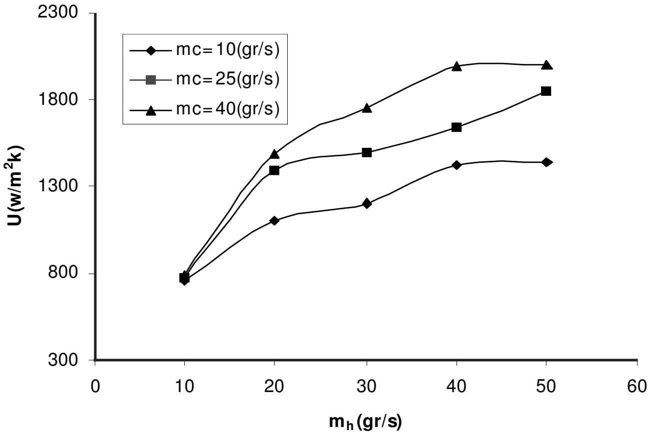

Fig. 5. Effect of hot and cold flow rate on overall heat transfer coefficient of nanofluids

Fig. 6 shows overall heat transfer coefficient of nanofluid and distilled water *versus* hot fluid mass flow rate. From this figure it is clear that for a constant mass flow rate, heat transfer coefficients of nanofluid are much higher than distilled water. For example at the m_h = 30 gr/s and m_c = 40 gr/s, the heat transfer coefficient of nanofluid is about 18 % higher than distilled water.

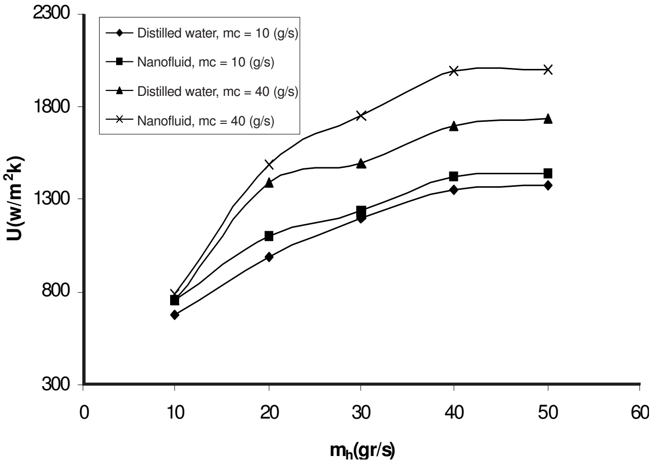

Fig. 6. Comparison between heat transfer coefficient of distilled water and nanofluid

Conclusion

In this study experimental studies have been developed to calculate the overall heat transfer coefficient and heat transfer rate of ZnO/water nanofluid in a U-type heat exchangers. The effects of some important parameters such as hot and cold mass flow rate on heat transfer parameters have been investigated under laminar conditions. Overall heat transfer coefficient of nanofluid increases with increase in the hot and cold mass flow rates.

For a given hot or cold flow rate, the heat transfer rate and total heat transfer coefficient of the nanofluid is higher than the distilled water. Increasing the hot fluid flow rate leads to an increase in the heat transfer rate and results in an increase in the heat transfer coefficient.

For a given hot fluid flow rate; the increase in the overall heat transfer coefficient is more forcible at high cold flow rate. For example in the m_{cold} = 10 gr/s and m_{hot} = gr/s the increase in U is 7.5 % but in the m_{cold} = 40 gr/s and m_{hot} gr/s, the increase is 14.1 %.

In a constant mass flow rate, heat transfer coefficients of nanofluid are much higher than base fluid (distilled water). For example in a double pipe U-type heat exchanger, at the m_h = 30 gr/s and m_c = 40 gr/s the heat transfer coefficient of nanofluid is about 18 % higher than distilled water.

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