Heat Transfer Enhancement by using Nanofluid in Spiral Plate Heat Exchanger

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***Abstract*—Nano particle in conventional fluid, called nanofluid have been the subject of interesting study in the research field since the discovery of the anomalous thermal behavior of these fluids. The enhancing thermal conductivity of these fluid in small particle concentration was surprising. This article present the heat transfer enhancement using Aluminium oxide-water nanofluid in a spiral Plate heat exchanger experimentally and compare the parameter with conventional fluid. Also numerical analysis is made by considering without Brownian motion and with Brownian motion.**

Keywords*—Nanofluid, spiral plate heat exchchanger, thermal conductivity

I. INTRODUCTION

Thermal properties of liquids play a decisive role in both heating and cooling applications in industrial processes. Thermal conductivity of a liquid is an important physical property that decides its heat transfer performance. Conventional heat transfer fluids have inherently poor thermal conductivity which makes them inadequate for ultra-high cooling applications. Scientists have tried to enhance the inherently poor thermal conductivity of these conventional heat transfer fluids using solid additives following the classical effective medium theory (Maxwell, 1873) for effective properties of mixtures. Fine tuning of the dimensions of these solid suspensions to millimeter and micrometer ranges for getting better heat transfer performance have failed because of the drawbacks such as still low thermal conductivity, particle sedimentation, corrosion of components of machines, particle clogging, excessive pressure drop etc. Down scaling of particle sizes continued in the search for new types of fluid suspensions having enhanced thermal properties as well as heat transfer performance

It is obvious from a survey of thermal properties that all liquid coolants used today as heat transfer fluids shows extremely poor thermal conductivity (with the exception of liquid metal, which cannot be used at most of the pertinent useful temperature ranges). It is worth saying that all of the efforts to increase heat transfer by creating turbulence, increasing area, etc., will be limited by the inherent restriction of the thermal conductivity of the fluid. Thus, efforts will be made to increase the thermal conduction behavior of cooling fluids. Maxwell [1] was a pioneer in this area who presented a theoretical basis for calculating the effective thermal conductivity of suspension. His efforts were followed by numerous theoretical and experimental studies, such as those by Hamilton-Crosser [2] and Wasp [3]. These models work very well in predicting the thermal conductivity of slurries. However, all of these studies were limited to the suspension of micro-to macro-sized particles

The emergence of nanofluids along with modern materials technology provided the opportunity to produce nanometer-sized particles which are quite different from the parent material in mechanical, thermal, electrical, and optical properties. Thus, nanofluid technology coupled with new heat-transfer-related studies on micro channel flow [4] has provided a new option of revisiting suspensions of nanoparticles. The first proposition in this area was came from Argonne National Laboratory (ANL) through the seminal work of Choi [5], who designated the nanoparticle suspension a nanofluid. From a purist's point of view, this designation may not be acceptable-every fluid is "nano" because of its molecular chains-but the term has been accepted and become popular in the scientific community.

II. LITERATURE REVIEW

Wang et al. [6] attributed the enhancement to particle motion, surface action, and electro-kinetic effects. The hydrodynamic force in the form of micro-convection can also be a cause of the enhancement. He also showed that Brownian motion is not a significant contributor to the heat transfer enhancement.

Keblinski et al. [7] look at the various possible enhancement mechanisms. He showed that liquid layering around the particle could give a path for rapid conduction. The mechanism of ballistic heat transport gains significance because the phonon mean free path is of the order of nano-particle dimensions. Liquid layering theory was shown to be promising, but it uses an adjustable parameter of the thickness of the liquid layer. He also showed that even though the Brownian motion appears to be a probable mechanism, results of a time scale study led to its rejection.

Meibo Xing et al [8] investigated the thermal conductivities of three types of carbon nanotubes (CNT)-nanofluids with volume concentration from 0.05 to 0.48 vol% at the temperatures of 10 to 60^0 C by experiments. The experimental results show that the thermal conductivities of CNTs-nanofluids are strongly dependent on the aspect ratio, concentration and temperature. The existent models for predicting thermal conductivity of CNT-nanofluid are compared with the experimental data. The results show that predictive values with those models underestimate or overestimate the thermal conductivity in terms of the experimental results. A novel thermal conductivity predictive model is proposed with experimental data. In the proposed model, the straightness ratio of the CNTs is modified by considering two factors of the concentration and length of CNTs, and temperature effect is also introduced. The predictive results indicate that the proposed model agrees with all the experimental data points within a ±5% error band.

Laura Fedeleet. al. [9] in their studies experimentally investigates on stability, dynamic viscosity and thermal conductivity of water-based nanofluids containing TiO_2 nanoparticles is done. Four different nanoparticle concentrations are studied (1 wt%, 10 wt%, 20 wt% and 35 wt%) and the considered experimental temperature ranges are between 283 K and 343 K and between 293 K and 353 K for viscosity and conductivity measurements, respectively, with steps of 10 K. All the fluids result quite stable in a static situation and completely stable after sonication for 1 h. The average particle diameter is 76 nm and no aggregations are found. They found that measured thermal conductivity of TiO_2-water nanofluids increases with mass concentration and with temperature. The effect of increasing conductivity is more evident at higher temperatures

Lee et al. [10] in their study used suspended CuO and Al_2O_3 (18.6 and 23.6 nm, 24.4 and 38.4 nm for them, respectively) with two different base fluids: water and ethylene glycol (EG) and obtained four combinations of nanofluids: CuO in water, CuO in EG, Al_2O_3 in water and Al_2O_3 in EG. Their experimental results showed that nanofluids have substantially higher thermal conductivities than the same liquids without nanoparticles. The CuO/EG mixture showed enhancement of more than 20% at 4 vol% of nanoparticles. In the low volume fraction range (<0.05 in test), the thermal conductivity ratios increase almost linearly with volume fraction. Although the size of Al_2O_3 particle is smaller than that of CuO, CuO-nanofluids exhibited better thermal conductivity values than Al_2O_3-nanofluids; no explanation is available for this observation at this time.

Das et al. [16] examined the effect of temperature on thermal conductivity enhancement for nanofluids containing Al_2O_3 (38.4 nm) or CuO (28.6 nm) through an experimental investigation using temperature oscillation method. They observed that a 2 to 4-fold increase in thermal conductivity can take place over the temperature range of 21 ◦C to 52◦C. The results suggest the application of nanofluids as cooling fluids for devices with high energy density where the cooling fluid is likely to work at a temperature higher than the room temperature. They also mention that the inherently stochastic motion of nanoparticles could be a probable explanation for the thermal conductivity enhancement since smaller particles show greater enhancements of thermal conductivity with temperature than do larger particles.

III. DESCRIPTION OF THE EXPERIMENT

The experimental setup consists of spiral plate heat exchanger with support to with stand the load and a thermocouple unit consists of 4 thermocouples with digital display to measure the different temperatures at inlet and outlet locations. A water heater immersed in the hot fluid storage tank supply hot water continuously at steady temperature. The temperature of hot fluid supplied to the heat exchanger is maintained about 60-90° C. Control valves are provided at inlet locations to vary the flow rate of hot and cold fluid. The dimensions of heat exchanger are shown in the Table 1. The hot fluid inlet pipe from the hot water tank is connected at the center core of the spiral plate heat exchanger and the outlet pipe is taken from periphery of the spiral plate heat exchanger as shown in the fig.1. A flow regulating valve is provided at the hot fluid inlet of the heat exchanger. The cold fluid connection is taken from the cold fluid tank and inlet pipe is connected to the periphery of the exchanger and the outlet is taken from the centre of the heat exchanger. Thus the counter flow of the fluid is achieved as shown in the fig.1. A schematic arrangement of the experimental set up is shown in fig.2. The cold fluid is supplied at room temperature from cold fluid tank. The flow of hot and cold fluid is varied using control valves C1 and C2 respectively. Thermocouple T1 and T3 are used to measure inlet temperature of hot and cold fluids respectively; T2 and T4 are used to measure the outlet temperatures of hot and cold fluids respectively.

The experiment starts with the measurement of heat transfer parameters of conventional fluid. When the temperature in the hot fluid tank reaches a steady temperature open the control valve provided at the inlet of exchanger. Open the control valve of cold fluid inlet and keep the flow at a specific rate. Record the temperature of the hot fluid inlet, cold fluid inlet, hot fluid outlet and cold fluid outlet using thermocouples T1, T3, T2 and T4 respectively. By keeping the inlet hot fluid flow rate constant vary inlet cold fluid flow rate using control valve and measure the measure the temperature of inlet and outlet fluid as explained above. For different cold fluid flow rate, the temperatures at the inlet and outlet of hot and cold fluids are to be recorded after achieving the steady state.

Measurement of the heat transfer parameter of nanofluid is the second step. Prepare the nanofluid using the Al_2O_3 nano particle in the particular volume fraction required for the experiment. The complete dispersion of the nano particle is ensured by the proper mixing of the mixing arrangement. Remove the water in the heat exchanger completely before starting the experiment. When the temperature in the hot fluid tank reaches a steady temperature open the control valve provided at the inlet of exchanger. Open the control valve of nanofluid inlet and keep the flow at a specific rate. Measure the temperature of the hot fluid inlet, nanofluid inlet, hot fluid outlet and nanofluid outlet using thermocouples T1, T3, T2 and T4 respectively. By keeping the inlet hot fluid flow rate constant vary inlet nanofluid flow rate using control valve and record the temperatures of inlet and outlet fluid. For different cold fluid flow rate, the temperatures at the inlet and outlet of hot and cold fluids are to be recorded after achieving the steady state. Homogeneity of the mixture has been tested by measuring density of the nanofluid at inlet and outlet of spiral plate heat exchanger which is within 1% alteration.

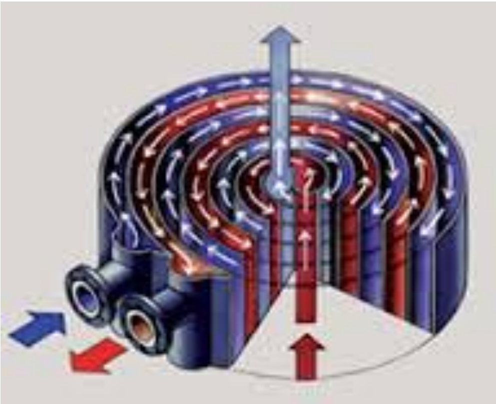

Fig.1: Flow pattern for counter flow arrangement in spiral plate heat exchanger

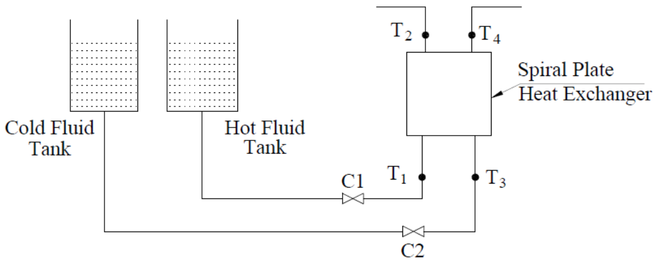

Fig.2: Schematic arrangement of experimental setup

Table 3.1 Dimensions of Spiral Plate Heat Exchanger

Parameters	Dimensions
Plate width, m	0.200
Plate Thickness, m	0.002
Mean channel spacing, m	0.020
Mean hydraulic diameter, m	0.036
Heat Transfer Area, m^2	0.3506

A. *Selection of Material*

Operating temperature of heat exchanger is in the region of 30 to 150 ^{0}C. Mild carbon steels can be used till 427^{0}C. Above this temperature, after prolonged exposure graphitization phenomena occurs. That is Pearlite component in the steel is converted into Graphite.

Since graphite is brittle material failure happens. So based on the operating temperature and weldability mild carbon steel is selected.

B. *Thermophysical properties of nanofluid*

The thermophysical properties of nanofluids, such as density, thermal conductivity, specific heat, and viscosity, have been calculated by using the formulas as summarized below.

The density of the nanofluids has been calculated by using the formula given by Buongiorno [11]:

$$\rho_{nf} = (1 - \varphi)\,\rho_f + \varphi\rho_p. \quad (1)$$

The specific heat of the nanofluid has also been calculated by using the formula by Buongiorno [11] is as follows:

$$C_{nf} = \frac{(1-\varphi)\,\rho_f C_f + \varphi\rho_p C_p}{\rho_{nf}} \quad (2)$$

The thermal conductivity equation given by Hamilton and Crosser [2] has been used for calculation purposes for the case when Brownian motion was not considered. Although this thermal conductivity model was given for mixtures containing micrometer sized particles, Zhang et al. [13] have shown that this model predicts the thermal conductivity for nanofluids accurately. In the following equation, n is the shape factor and is equal to 3 for spherical nanoparticles:

$$\frac{k_{nf}}{k_f} = \frac{k_p + (n-1)k_f - (n-1)\varphi(k_f - k_p)}{k_p + (n-1)k_f + \varphi(k_f - k_p)} \quad (3)$$

$$k_{nf} = k_f + 3\varphi\,\frac{k_p - k_f}{2k_f + k_p - \varphi(k_p - k_f)}\,k_f + \quad (4)$$
$$5x10^4 \beta\rho_f C_f \varphi x \sqrt{\frac{k_b T}{2\rho_p r_p}}\,[(-134.63 + 1722.3\varphi) + (0.4705 - 6.4\varphi)T]$$

The parameter β is related to the nanoparticle Brownian motion and was determined empirically as

$$\beta = 0.0011(100\,\varphi)^{-0.7272}, \text{ for } \varphi > 0.01 \quad (5)$$

The viscosity of the nanofluid was calculated by using the Batchelor correlation [12] as very dilute suspensions were used in this study:

$$\mu_{nf} = (1 + 2.5\varphi + 6.2\varphi^2)\,\mu_f \quad (6)$$

C. *Calculation Methodology*

The following basic relations were used for calculating the overall heat transfer coefficients and individual heat transfer coefficients on the cold side and hot side.

$$Q = m_h \, x \, C_{Ph} \, x \, (T_{hi} - T_{ho}) \quad (7)$$

$$U = \frac{Q}{A\,x(\Delta T)_{lm}} \quad (8)$$

$$\text{Mass velocity, } G_s = \frac{m_c}{A} \quad (9)$$

$$N_u = 2.0\,G_z^{0.33} \quad (10)$$

This correlation between Nusselt Number (Nu) and Graetz Number (Gz) is adopted from the book of McCabe et al. (2001)

$$N_u = \frac{h_h x d_e}{k_h} \quad (11)$$

$$G_z = \frac{m x c_p}{k x L} \quad (12)$$

$$\frac{1}{U} = \frac{1}{h_h} + \frac{t}{k_{ms}} + \frac{1}{h_c} \quad (13)$$

IV. RESULTS AND DISCUSSION

A. *Mass velocity Vs Heat Transfer Coefficient (conventional fluid)*

In this study conventional fluid is taken as ordinary water. The hot fluid mass flow rate is kept constant and cold fluid flow rate is varied. The effect of heat transfer rate on mass velocity is shown in figure 3. It is observed that the heat transfer rate increases with increasing mass velocity of cold fluid.

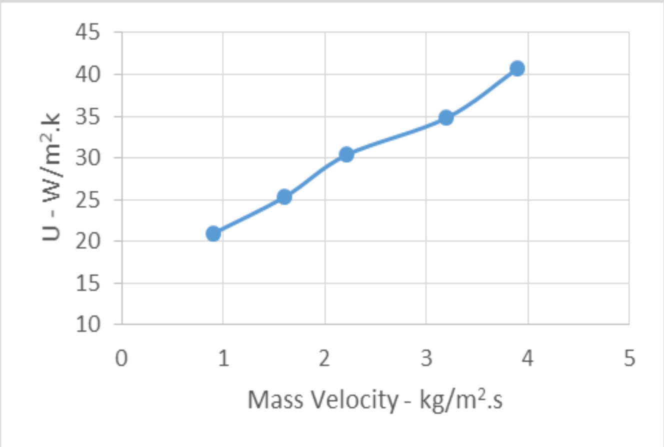

Fig.3: Variation of heat transfer coefficient with mass velocity

B. *Mass velocity Vs Heat Transfer Coefficient (Nanofluid)*

In this study the conventional fluid in the hot side fluid is taken as ordinary water and the cold side fluid side is taken as water+Al_2O_3 nano fluid. The hot fluid mass flow rate is kept constant and cold fluid flow rate is varied. The effect of heat transfer rate of nanofluid on mass velocity is shown in figure 4. It is observed that the heat transfer rate increases with increasing mass velocity of cold fluid. The increased heat transfer is due to the increase in Reynolds number and turbulence of fluid.

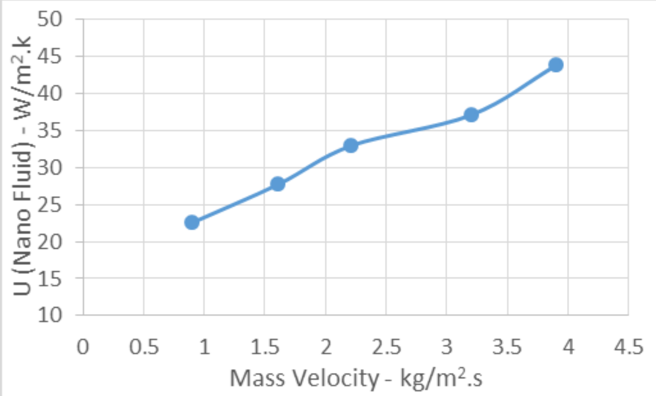

Fig.4: Variation of heat transfer coefficient of nanofluid with mass velocty

C. *Comparison of heat transfer coefficient of conventional fluid and nanofluid with Mass velocity*

The comparison of heat transfer coefficient of conventional fluid and nanofluid is shown in figure 4. In this study the conventional fluid in the hot side fluid is taken as ordinary water and the cold side fluid side is taken as water+Al_2O_3 nanofluid. The hot fluid mass flow rate is kept constant and cold fluid flow rate is varied. The effect of heat transfer rate of nanofluid on mass velocity is shown in figure 5. It is observed that the heat transfer rate increases with increasing mass velocity of cold fluid. The increased specific surface area of nanoparticle and the increase in the effective thermal conductivity of nanofluid is the reason for increased heat transfer rate.

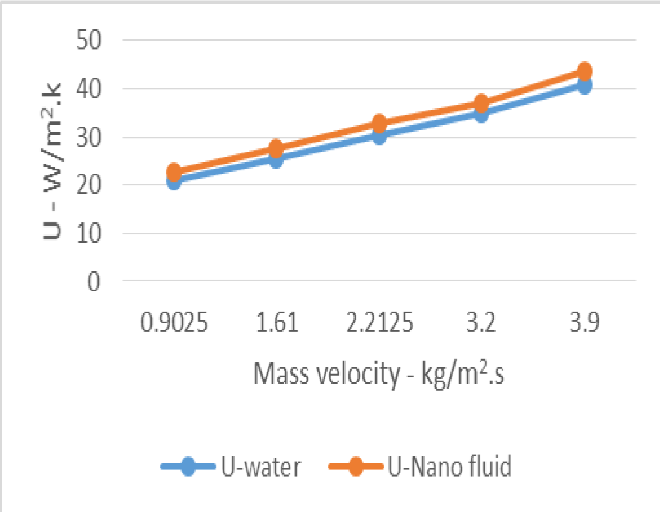

Fig.5: variation of heat transfer coefficient for water and nanofluid with mass velocity

D. *Comparison of heat transfer coefficient of nanofluid with Brownian motion and without Brownian motion*

The comparison of heat transfer coefficient of nanofluid with Brownian motion and without Brownian motion is shown in fig.6. The heat transfer coefficient of nanofluid with Brownian motion is greater than that of without Brownian motion. The increase in effective thermal conductivity due to Brownian motion is the reason for the increase in thermal conductivity of nanofluid with Brownian motion

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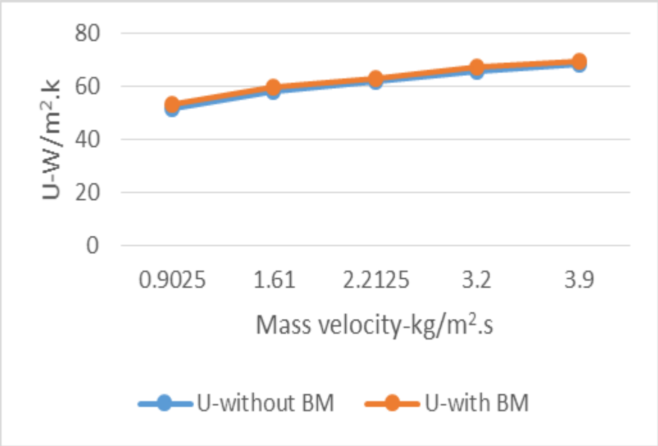

Fig.6: variation of heat transfer coefficient for nanofluid with Brownian motion and without Brownian motion with mass velocity

CONCLUSION

Heat transfer enhancement by nanofluid in a spiral plate heat exchanger were studied. The spiral plate heat exchangers were designed, fabricated, and tested. Heat transfer coefficient for water was studied for different mass flow rate using physical model. The heat transfer enhancement by using nanofluid in the spiral plate heat exchanger is studied for different mass flow rate. The heat transfer coefficient of conventional fluid and nanofluid was compared.

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