Heat Transfer Enhancement by using ZnO-Water Nanofluid in a Concentric Tube Heat Exchanger under Forced Convection Conditions

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Abstract- Conventional heat transfer fluids such as water, mineral oil, and ethylene glycol play an important role in many industries such as power generation, chemical production, air conditioning, transportation, and microelectronics. However, their low thermal conductivities have hampered the development of energy-efficient heat transfer fluids that are required in a plethora of heat transfer applications. It has been found from literature survey that the heat transfer properties of these conventional fluids can be significantly enhanced by dispersing nanometer-sized solid particles. The suspended metallic particles change the transport properties and heat transfer characteristics of the base fluid. Thus the research has been focused on the preparation of nano-fluids using metal and metal oxide nanoparticles. In the present study ZnO nano particles are prepared by using sol-gel technique. The raw material is passed through different stages such as dissolving, preparation of solution, formation of gel, filtration and drying to get the nano sized particles. To remove the liquid traces completely from nanoparticles they are sintered. The ZnO-water nanofluid is prepared at different volumetric concentration. The experiments are conducted in a concentric tube heat exchanger to study the heat transfer rates of ZnO-water nanofluid for different flow rates and for different volume fractions of nano-particles in the base fluid. The experimental results are compared with the base fluid. The nano-fluid properties are evaluated with correlations available in the literature to find the theoretical heat transfer coefficients.

Keywords – ZnO nanofluid, heat transfer in nanofluid, Concentric tube heat exchanger

I. INTRODUCTION

Particles of size range 1-100 nm are considered nano-scale. These nanoparticles, and structures and devices comprised of them, display unique mechanical, optical, electrical, and magnetic properties that differ radically from the corresponding bulk material. Applications of nanostructured materials include catalysts, electrolyte membranes, films, and fibers. Current intense research in nanoparticles has created a great demand for their efficient production. Many researchers have investigated the heat transfer performance and flow characteristics of various nanofluids with different nanoparticles and base fluid materials. Pak and Cho [1] investigated experimentally the heat transfer performance of Al_2O_3 and TiO_2 nanoparticles dispersed in water flowing in a horizontal circular tube with a constant heat flux under turbulent flow conditions. The results showed that the Nusselt number of nanofluids increased with increasing Reynolds number and the volume concentration.. Lee et al. [2] observed the enhancement of thermal conductivity of nanofluids while using CuO and Al_2O_3 nanoparticles with water and ethylene glycol compared to base fluids only. The thermal conductivities of nanofluids with CuO and Al_2O_3 nanoparticles have been determined experimentally using steady-state parallel-plate technique by Wang et al. [3], for different base fluids such as water, ethylene glycol and engine oil. The thermal conductivity of these nanofluids increased with increasing volume fraction of the nanoparticles. Xuan and Li [4] experimentally investigated flow and convective heat transfer characteristics for Cu-water based nanofluids through a straight tube with a constant heat flux at the wall. Results showed that the nanofluids give substantial enhancement of the heat transfer rate compared to pure water. Xuan and Roetzel [5] concluded from their findings that the heat transfer enhancement is due to increase in thermal conductivity or due to thermal dispersion caused by random motion of the particles coupled with enhanced thermal conductivity. Choi et al. [6] studied the enhancement of thermal conductivity of carbon nanotube–oil mixture nanofluid at room temperature. Xie et al. [7] dispersed carbon nanotube in distilled water and ethylene glycol and concluded that a small amount of carbon nanotubes have significantly increased the thermal conductivities compared to base fluid. Chien et al. [8] investigated gold (17 nm)/water nanofluids flowing in a disk-shaped miniature heat pipe with diameter of 9 mm and height of 2 mm. Their data showed that the thermal resistance of the heat pipe fell appreciably with increased nanoparticle concentration. Das et al. [9] investigated the variation of thermal conductivity of nanofluids (Al_2O_3-water and CuO-water) with temperature using temperature oscillation technique. They observed an increase in thermal conductivity with temperature. Xue [10] developed a novel approach in the modeling of nanofluid by considering the particles to be ellipsoids interacting with spherical fluid particles. Yu and choi [11] introduced the classical Maxwell model in which the liquid layer around the particle behaves like as a solid. Wen and Ding [12] reported experimental results for the convective heat transfer of γ -Al_2O_3 (27-56 nm)/water based nanofluids flowing through a copper tube laminar regime. They found that the inclusion of Al_2O_3 particles can significantly enhance the convective heat transfer coefficient. Tsai et al. [13] also employed aqueous solutions of various sized gold nanoparticles, which were prepared by the reduction of HAuCl4 with tri sodium citrate and tannic acid. Hwang et al. [14] through experimental investigation of flow and convective heat transfer characteristics of Al_2O_3/water nanofluid, with convective heat transfer characteristics of Al_2O_3/water nanofluid with particles varying in the range of 0.01–0.3% in a circular tube of 1.812 mm inner diameter with the constant heat flux in fully developed laminar regime reported improvement in convective heat transfer coefficient in the thermally fully developed regime. Yang et al. [15] measured experimentally the convective heat transfer coefficients of several nanoparticle-in-liquid dispersions under laminar flow in a horizontal tube heat exchanger. Assael et al. [16] studied experimentally the thermal conductivity of nanofluids using the transient hot-wire method. They observed a significant increase in thermal conductivity of nanofluid. Koo and Kleinstreuer [17] have shown that the Brownian motion has more impact on the thermal properties of nanofluid than thermo-phoresis. However Boungiorno [18] showed analytically that thermal dispersion has a negligible effect on increase in convective heat transfer rather Brownian diffusion and thermo-phoresis are the main mechanisms that contribute to the heat transfer enhancement. Heris et al. [19] investigated laminar flow of CuO/water and Al_2O_3/water nanofluids through a 1 m annular copper tube with 6 mm inner diameter and with 0.5 mm thickness and 32 mm diameter outer stainless steel tube, where saturated steam was circulated to create a constant wall temperature boundary condition rather than the constant heat flux condition employed by other researchers. Comparison of experimental results showed that the heat transfer coefficient enhanced with increasing volume fraction of nanoparticles, as well as Peclet number, while Al_2O_3/water showed more enhancement. Heris et al. [19] claimed that the heat transfer enhancement of nanofluids is not only caused by the thermal conductivity increase, but also attributed to other factors such as dispersion and chaotic movement of nanoparticles, Brownian motion and particle migration, and so on. Zhang et al. [20] measured the thermal conductivity and thermal diffusivity of Au-toluene, Al_2O_3-water, TiO_2-water, CuO-water and carbon nanotubes-water nanofluids using the transient short-hot-wire technique. They observed no enhancement in the thermal conductivity as well as thermal diffusivity of nanofluids, above that of predictions of the Hamilton-Crosser model [21]. Mirmasoumi and Behzadmehr [22] have studied the effects of nanoparticle mean diameter on the heat transfer and flow behavior into a horizontal tube under laminar mixed convection condition. Their calculated results demonstrate that the convection heat transfer coefficient significantly increases with decreasing the nanoparticles means diameter. Zamzamian et al. [23] investigated the effects of forced convective heat transfer coefficient with Al_2O_3/EG and CuO/EG nanofluid in double pipe and plate heat exchangers. Their results indicate that increasing the nanoparticle concentration and temperature could enhance the convective heat transfer coefficient of nanofluid, leading to a 2–50% enhancement in convective heat transfer coefficient of the nanofluid. The objective of the present work is to provide improvements through nano fluids in place of pure working fluid in heat exchangers. In this study, ZnO nanoparticles are prepared by sol-gel method and the nanoparticle with concentration up to 0.5% by volume has been selected as a coolant in a typical horizontal double-tube heat exchanger because of their reasonably good thermal properties and easy availability. Water has been chosen as heat transfer base fluid. The experiments are conducted in the heat exchanger for different concentrations of nanoparticles and Reynolds numbers.

II. PREPARATION OF ZINC OXIDE NANO-PARICLES BY SOL-GEL METHOD

Materials required: zinc nitrate (or chloride), ammonium hydroxide, cetyl trimethyl ammonium bromide (CTB), polyvinyl-pyrolidene (PVP), burette, 250ml beaker, magnetic needle, magnetic stirrer, whattmann filter paper, sample bags, crucible,

Step 1: weigh 16g of zinc nitrate (or chloride) and transfer it into 250 ml beaker and add 30 ml isopropyl alcohol to it and stir the contents moderately for about 20 min to get a clear solution of copper sulfate

Step 2: weigh 3.2 g of cetyl trimethyl ammonium bromide and transfer it into a 100 ml beaker and add 20 ml of isopropyl alcohol and stir the contents thoroughly. In case CTB does not dissolve add few drops of HCl and stir the contents for 15 min.

Step 3: Weigh 2.2 g of polyvinyl pyrolidene (PVP) and transfer it into a 100 ml beaker and add 20 ml of isopropyl alcohol and stir the contents thoroughly for about 15 min to get a clear solution.

Step 4: Transfer step 2 solution into a 50 ml burette and add drop-wise the solution of CTAB to Step 1 contents while stirring moderately for about 30 min.

Step 5: Transfer step 3 solution into a 50 ml burette and add drop-wise the solution of PVP to Step 1 contents while stirring moderately for about 30 min.
Step 6: Take 35 ml of ammonium hydroxide in burette and then add drop-wise to step 1 content while stirring the contents moderately
Step 7: A whitish precipitate will form and leave the contents stirring for about 30 min to get the homogeneous
Step 8: Filter the precipitate using a whatman filter paper and wash the precipitate with distilled water at least 5 to 6 times
Step 9: Leave the precipitate by covering the funnel by petri dish over night
Step 10: the dried precipitate can be transferred on to a petri dish and dry the precipitate by covering with another petri dish cover in oven at 70^0C for 8 hours
Step 11: Collect carefully the dried precipitate and weigh it and note down the value. Then sinter it at temperatures 200^0C for 3 h in air ambient. Check that the crucible has a cap to avoid the dust particle.
Step 12: After cooling down transfer and the material and weigh it and note down the value in lab note book. Check the weight loss before and after.
Step 13: Make the each sintered material into 2 parts one for the characterization (1g) and remaining for the testing for heat exchange experiments.

Figure 1 (a) ZnO nanoparticles before sintering (b) ZnO nanoparticles after sintering

III. PREPARATION OF ZNO-WATER NANOFLUID

Choi et.al [6] pioneered the work in the nanofluids by dispersing nanometer sized particles into liquids. They suggested that compared with the suspension of larger particles, nanoparticles can be kept in dispersions for much longer time. Because nanoparticles are so small, they may act like macromolecules in solution, dramatically reducing erosion and clogging and their larger surface areas improve heat transfer. After that, numerous experimental results have been reported and this concept has been proved. The step by step procedure is given below.

- Calculate the required concentration of nanoparticles and take the mixer proportions into a small beaker.
- Add 10% of surfactant (CTAB- Cetyl trimethyl ammonium bromide) to stabilize the nanofluid.
- Now fix the beaker under the probe.
- Maintain some gap between the probe and the glass beaker to produce vibrations and also to avoid breakage of the glass beaker.
- The timer is set to 30seconds on time and 5seconds off time.
- Now switch on the probe sonicator and set it to 15times which is one cycle.
- Vibration of probe mixes the nanoparticles with the base fluid.
- As the mixing continues the beaker is heated up because of the vibration.
- So Place the beaker in an ice bath so that it gets cooled or it transfers the heat produced in the beaker.
- Repeat the above process at least for four cycles to get a completely dispersed nano fluid.
- Use the nanofluid before the nanoparticles settle down. .

IV.EXPERIMENTAL SETUP

A. Description of experimental facility

The system consists of a double pipe heat exchanger. The inner tube is made of copper and the outer tube is made of stainless steel. It consists of a heating unit to heat the water, and temperature measurement system. The temperature measurement system consists of 4 thermocouples, placed at the inlet and outlet of the inner and outer tube respectively. The hot water flows through the inner tube and the nano fluid/other fluid flows through the annulus. Each flow loop includes a pump with a flow meter, a reservoir and a bypass valve to maintain the required flow rate. To design a project that could be used to transfer heat from hot water in a heat exchanger to nano-fluid stored in a separate tank and make temperature calibrations for the same by employing two thermocouples. Also, flow meters will be installed in the pipes carrying nanofluid to check its flowing rate. The complete system will be very dynamic and easy to use. Mechanical structured design is shown in Fig. 2. As with any process the analysis of a heat exchanger begins with an energy and material balance. Before doing a complete energy balance a few assumptions can be made. The first assumption is that the energy lost to the surroundings from the cooling water is negligible. We also assume negligible potential or kinetic energy changes and constant physical properties such as specific heats and density.

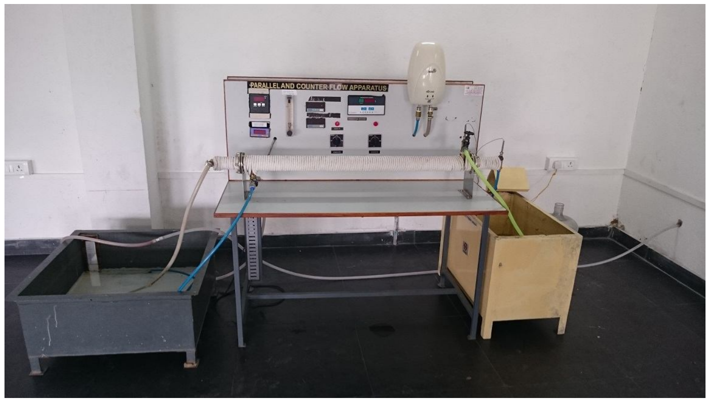

Figure 2 Experimental Setup

B. Experimental Procedure

The main switch is switched on and the console and heater is also turned on. The cold water from the reservoir is pumped to the heat exchanger by maintaining a constant flow rate. The hot water flow rate valve is kept open. After attaining steady state conditions, the inlet and outlet temperature readings of both the pipes are noted down from the temperature scanner which can be run manually or kept in auto mode. The flow rate of cold water is known with the help of a water flow sensor. The hot water flow rate can be adjusted according to the requirements with the help of a hot water flow meter. The readings of both hot and cold water flow rates are noted down. This completes the first set of readings. Depending upon the requirement of the cold water flow rate, next set of readings can be noted down.

C. Overall Heat Transfer Coefficient

The determination of the overall heat-transfer coefficient is necessary in order to determine the heat transferred from the inner pipe to the outer pipe. As the heat exchanger is relatively new the fouling resistances are neglected in the present work. For a double-pipe heat exchanger the overall heat transfer coefficient based on outer radius, U_0, can be expressed as

$$\frac{1}{U_0} = \frac{1}{h_o} + \frac{r_o}{k}\ln\frac{r_o}{r_i} + \frac{1}{h_i}\frac{r_o}{r_i} \quad (1)$$

Where h_0 is heat transfer coefficient of fluid flowing through annulus, h_i is heat transfer coefficient of fluid flowing through pipe, k is the thermal conductivity of inner pipe material, r_o is outer radius of pipe and r_i is inner radius of pipe

D. Experimental Overall Heat Transfer Coefficient

The procedure to calculate the experimental overall heat transfer coefficient ($U_{0,E}$) is given below. In a heat exchanger the log-mean temperature difference is the appropriate average temperature difference to use in heat transfer calculations. The equation for the log-mean temperature difference is

$$LMTD = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} \quad (2)$$

Where $\Delta T_1 = T_{h_i} - T_{c_i}$ and $\Delta T_2 = T_{h_o} - T_{c_o}$; T_{ci} is the cold water inlet temperature, T_{co} is the cold water outlet temperature, T_{hi} is the hot water inlet temperature and T_{ho} is the hot water outlet temperature

The heat transfer rate (Q) can be calculated by

$$Q = m_h C_{p_h} (T_{h_i} - T_{h_o}) \quad (3)$$

where m_h mass flow rate of hot fluid and $C_{p,h}$ Specific heat of hot fluid

The experimental overall heat transfer coefficient ($U_{0,E}$) can be determined by

$$Q = U_{o,E}\dot{A}_o(\text{LMTD}) \quad (4)$$

where A_o is the outer surface area of the pipe.

E. Theoretical Overall Heat Transfer Coefficient

The procedure to calculate the theoretical overall heat transfer coefficient ($U_{0,\,T}$) is given below. The properties density (ρ), kinematic viscosity (γ), Prandtl number (Pr) and thermal conductivity (k) of cold fluid can be calculated at average temperature of $T_f = \frac{Tci+Tco}{2}$.

The velocity of the cold fluid is calculated by

$$Q = AV \quad (5)$$

Where Q=flow rate

A= area of cross section of annulus = $\frac{\pi}{4}\ (D_i^2 - d_o^2\ )$

V= velocity of fluid

The Reynolds number can be calculated by

$$R_e = \frac{V(D_i - d_o)}{\vartheta} \quad (6)$$

Where D_i inner diameter of outer pipe

The Nusselt number is calculated by Dittus-Boelter equation

$$N_u = 0.023 \times R_e^{0.8} \times P_r^n \qquad \text{(n=0.4 for heating)} \quad (7)$$

The heat transfer coefficient for cold water (h_o) is determined by

$$N_u = \frac{h_o(D_i - d_o)}{k_{water}} \quad (8)$$

The average temperature for hot fluid is calculated by

$$T_f = \frac{Thi+Tho}{2} \quad (9)$$

The velocity of the hot fluid is calculated by

$$Q = AV$$

The Reynolds number for hot fluid can be calculated by

$$R_e = \frac{VD}{\vartheta} \quad (10)$$

The Nusselt number for hot fluid is given by

$$N_u = 0.023 \times R_e^{0.8} \times P_r^n \qquad \text{(n=0.3 for cooling)} \quad (11)$$

The heat transfer coefficient for hot fluid is calculated by

$$N_u = \frac{h_i d_i}{k_{water}} \quad (12)$$

The theoretical overall heat transfer ($U_{0,T}$) can be determined by

$$\frac{1}{U_{0,T}} = \frac{1}{h_i}\frac{r_0}{r_i} + \frac{r_0}{k_{cu}}\ln\frac{r_0}{r_i} + \frac{1}{h_0} \quad (13)$$

F. Calibration of Experimental set up

The reliability and accuracy of the experimental system are estimated by using water as working fluid. The experimental and theoretical overall heat transfer coefficients are found by the procedure given above. As shown in Fig. 3, the good coincidence between the experimental results and the calculated values for water reveals that the precision of the experimental setup is good.

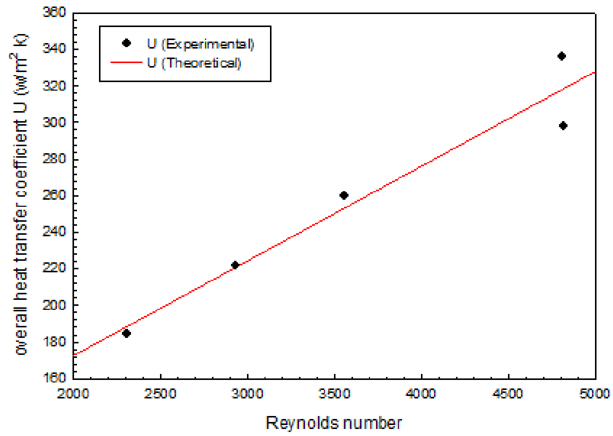

Figure 3 Calibration curve of experimental setup

IV. RESULTS AND DISCUSSION

ZnO nanoparticles are also prepared by using sol-gel technique undergoing same procedure, but zinc chloride is used as a raw material from which ZnO nanoparticles are extracted. Nanofluids are prepared at different volumetric concentrations (0.1 to 0.5%) by using probe sonicator. For the stability of nanoparticles 10% surfactant is added to the nanofluid. The experiment is conducted before the particles are settled down for different flow rates of nanofluids and different volume fractions of nanoparticles. The experimental overall heat transfer coefficients are calculated using the procedure given in the above section. . Fig. 4 shows the effect of Reynolds number of nano fluid flowing through the annulus on experimental overall heat transfer coefficient for different nanoparticle concentrations in base fluid stored in the vessel. It can be observed from curves of Figure 4, that the overall heat transfer coefficient is increased by 11% with volume fraction of 0.5 percent of ZnO nanoparticles compared with water. The increase in heat transfer coefficient is due to increase in thermal conductivity of water with the addition of nanoparticles, and also due to increase in heat transfer to the cold fluid due to random motion of nanoparticles suspended in water and availability of larger surface area with nano sized particles . The experimental results also indicate that the experimental heat transfer coefficient of ZnO-water nanofluid increases with the increase in volume fraction of nanoparticles in base fluid. The curves of the same figure show the same trend i.e., the heat transfer to the cold fluid increases with the increase in volume fraction of nanoparticles in the base fluid. As expected, it can be observed from figure 4 that the heat transfer coefficient of the nanofluid increases with the flow rate.

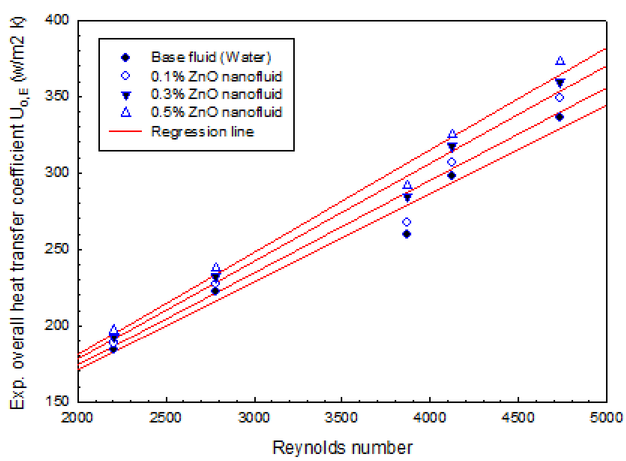

Figure 4 Variation of experimental overall heat transfer of ZnO nanofluids at different flow rates and volume fractions of nanoparticles

The properties of the nanofluid are calculated using the correlations available in literature. The thermal conductivity of nanofluid depends on thermal conductivity of both base fluid and nanoparticles material, volume fraction of nanoparticles, surface area of nanoparticles and shape of nanoparticles in the liquid. Hamilton and Crosser [21] developed a model for the effective thermal conductivity of two-component mixture. The theoretical overall heat transfer coefficients are calculated using the procedure given in the section IV. Fig.5 shows the effect of Reynolds number of nano fluid flowing through the annulus on theoretical overall heat transfer coefficient for different nanoparticle concentrations in base fluid.

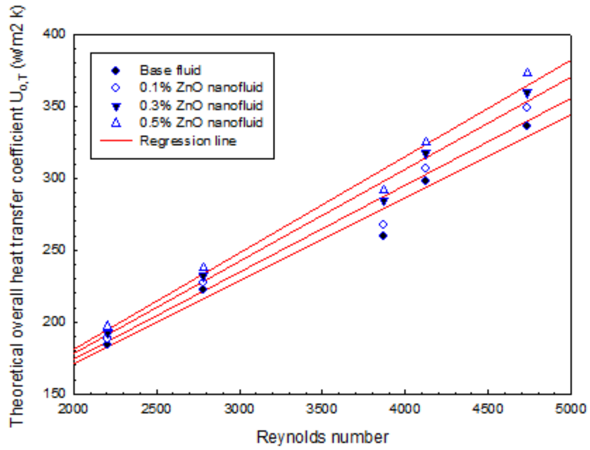

Figure 5 Variation of theoretical overall heat transfer of ZnO nanofluids at different flow rates and volume fractions of nanoparticles

V. CONCLUSIONS

ZnO nano particles are prepared by using a chemical method named as sol-gel technique. The raw material is passed through different stages such as dissolving, preparation of solution, formation of gel, filtration and drying to get the nano sized particles. To remove the liquid traces completely from nanoparticles they are sintered at 200°C for 3 hours. The nanofluids are prepared by using method given by choi at.el [6] in probe sonicator at different volumetric concentration (0.1 to 0.5%). For the stability of nanoparticles 10% of surfactant is added to the nanofluids. The experiment is conducted in a double pipe heat exchanger. Before conducting the experiment the heat exchanger is calibrated and then ZnO-water nanofluid is sent through annulus and readings are noted down. The nanofluid readings are compared with base fluid readings (water). The overall heat transfer coefficient for ZnO-water nanofluid is increased by 11% with volume fraction 0.5% compared with water. The increase in heat transfer coefficient is due to increase in thermal conductivity of water with the addition of nanoparticles, and also due to increase in heat transfer to the cold fluid due to random motion of nanoparticles suspended in water and availability of larger surface area with nano sized particles.

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