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ENHANCEMENT OF CONVECTION HEAT TRANSFER RATE USING NANO FLUID (Al_2O_3)

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***Abstract-*: *This project presents a study of increasing the thermal conductivity, convection heat transfer enhancement and effectiveness of floating head heat exchanger (FHHE) with Nano fluids (Al_2O_3). Nano fluid can be defined as a colloidal suspension of solid particles in a base fluid, where the particles have a characteristic length of less than 100 nm. Normally the characteristic length ranges from 1 to 100 nm. First studies have been directed towards the determination of the properties of nanofluids, especially their thermal conductivity, specific heat, volume concentration and viscosity. Experiments have been conducted with nanofluid (Al_2O_3) at various concentrations and temperature ranges, for the estimation of the heat transfer coefficient, specific heat and friction factor for water-based nanofluid. All the studies confirmed enhancement of the heat transfer coefficient with an increase in concentration. The experimental results have been compared with theoretical results of nanofluid (Al_2O_3 and TiO_2) at the same condition. Effectiveness of floating head heat exchanger with nanofluid (Al_2O_3) has been compared with effectiveness of floating head heat exchanger with normal water. It is observed that the concentration of the Nano fluid, the operating temperature, the particle size and shape, together with the material of the nanoparticle dispersed in the base liquid, have significant influence on the heat transfer coefficient. The experiment indicates a nominal increase in pressure drop with increase of concentration of nanoparticles (Al_2O_3).*

Keywords: Thermal Conductivity, Specific Heat, convection Heat Transfer, Nano fluids (AL_2O_3), Efficiency of floating head heat exchanger (FHHE).

1.INTRODUCTION

Nano fluid is envisioned to describe a fluid in which nanometer-sized particles are suspended in conventional heat transfer basic fluids. Conventional heat transfer fluids, including oil, water, and ethylene glycol mixture are poor heat transfer fluids, since the thermal conductivity of these fluids play important role on the heat transfer coefficient between the heat transfer medium and the heat transfer surface. Therefore numerous methods have been taken to improve the thermal conductivity of these fluids by suspending Nano/micro or larger-sized particle materials in liquids. Since the solid nanoparticles with typical length scales of 1–100 nm with high thermal conductivity are suspended in the base fluid (low thermal conductivity), have been shown to enhance effective thermal conductivity and the convective heat transfer coefficient of the base fluid. The thermal conductivity of the particle materials, metallic or nonmetallic such as Al_2O_3 CuO, Cu, SiO, TiO_2, are typically order-of-magnitude higher than the base fluids even at low concentrations, result in significant increases in the heat transfer coefficient. Therefore the effective thermal conductivity of Nano fluids is expected the enhanced heat transfer compared with conventional heat transfer liquids. Since the high thermal conductivity nanoparticles suspended in the base fluid which has a low thermal conductivity, remarkably increase thermal conductivity of Nano fluids. Researchers developed many models to tell how much that increase would be and many experiments have been conducted to compare experimental data with those analytical models. This still needs further research to develop a sophisticated theory to predict thermal conductivity of Nano fluids. But there exists some empirical correlations to calculate effective thermal conductivity of two-phase mixture. In the literature, the thermal conductivity enhancement ratio been defined as the ratio of thermal conductivity of the Nano fluid to the thermal conductivity of the base fluid (K_{eff}/K_1). Researches developed their thermal conductivity models based on the classical research of Maxwell who researched conduction through heteronomous media [1]. The effective thermal conductivity for a two-phase mixture consisting of a continuous and discontinuous phase has been conducted by Maxwell and the effective thermal conductivity K_{eff} is given by

$$K_{eff\ Maxwell} = \frac{2K_2+K_1+\o(K_2-K_1)}{2K_2+K_1-2\o(K_2-K_1)}K_1 \qquad (1)$$

Where K_1 and K_2 are thermal conductivity of the liquid and the particle respectively and $\O$ is the particle volume fraction. Maxwell derived his model based on the assumption that the discontinuous phase is spherical in shape and the thermal conductivity of Nano fluids depend on the thermal conductivity of spherical particles, the base fluid and the particle volume fraction. Hamilton and Crosser extended Maxwell work to cover none spherical particles and introduced the shape factor (n) which can be determined experimentally for different type of materials. The goal of their research was to develop a model as a function of particle shape, composition and the conductivity of both continuous and discontinuous phases [2]. Hamilton and Crosser model for a discontinuous phase (particles) dispersed in a continuous phase is:

$$K_{eff} = K_1 \left[\frac{k_2+(n-1)K_1-(n-1)\emptyset(k_1-k_2)}{k_2+(n-1)K_1-\emptyset(k_1-k_2)}\right] \quad (2)$$

Theoretical studies [3-10] show that thermal conductivity of Nano fluids depends on many factors such as particle volume fraction, particle material, particle size, particle shape, base fluid material, and temperature. Amount and types of additives and the acidity of the Nano fluid were also shown to be effective in the thermal conductivity enhancement.

1.1 Objectives of the Study

Objectives of the experiment are given below:

- Increasing the thermal conductivity (K) of the fluid by using nanoparticles (Al_2O_3)
- Increasing the convection heat transfer coefficient (h_0)
- Enhancement of the convection heat transfer rate in floating head heat exchanger
- Increasing the effectiveness of the floating head heat exchanger

2. METHODOLOGY

The system has been designed to increase the thermal conductivity of fluid and enhance the convection heat transfer rate in the cooling and heating system. It consists of a floating head heat exchanger, Nano fluid (Al_2O_3), base fluid (H_2O), pump, thermometer, flow measuring device (Rota meter), thermometer, and pipes, different types of joint, and electric heater.

2 .1 Assumptions

Assumptions of the experiment are given below:

- There are no viscosity effect on the Nano fluid flowing.
- Effects of density on Nano fluids are not considered.
- Size and shape of nanoparticles are not considered.
- Particle volume fraction is not considered.
- Assuming no conduction and radiation heat loss occurred from heat exchanger.
- Considering the flow of Nano fluid is uniform.
- Frictional losses are neglected

2.2 Equipment and Materials

Names of the Equipment and materials of experimental setup are following:

- Nanoparticle(AL_2O_3)
- Base fluid(H_2O)
- Magnetic stirrer
- Floating head heat exchanger
- Pump
- Thermocouples (Thermometers)
- Flow measuring device (Rota meter)
- Electric heater
- Pipes
- Different types of joint

2.3 Production Methods of Nanofluid

There are two stages of production method of Nano fluid [11-14].First is the production of the nanoparticles and second is the mixing of nanoparticles with base fluid.

Production of nanoparticles can be divided into two main categories, namely, physical synthesis and chemical synthesis. Yu *et al.* [15] listed the common production techniques of Nano fluids as follows. Physical Synthesis: Mechanical grinding, inert-gas-condensation technique. Chemical Synthesis: Chemical precipitation, chemical vapor deposition, micro-emulsions, spray pyrolysis, thermal spraying.

There are mainly two methods of Nano fluid production, namely, two-step technique and one-step technique. In the two-step technique, the first step is the production of nanoparticles and the second step is the dispersion of the nanoparticles in a base fluid. Two-step technique is advantageous when mass production of Nano fluids is considered, because at present, nanoparticles can be produced in large quantities by utilizing the technique of inert gas condensation. The main disadvantage of the two-step technique is that the nanoparticles form clusters during the preparation of the Nano fluid which prevents the proper dispersion of nanoparticles inside the base fluid. One-step technique combines the production of nanoparticles and dispersion of nanoparticles in the base fluid into a single step. There are some variations of this technique. In one of the common methods, named direct evaporation one-step method, the Nano fluid is produced by the solidification of the nanoparticles, which are initially gas phase, inside the base fluid. The dispersion characteristics of Nano fluids produced with one-step techniques are better than those produced with two-step technique. The main drawback of one-step techniques is that they are not proper for mass production, which limits their commercialization.

2.4 Experimental Setup

Fig.1 illustrates the Heat Exchanger experiment apparatus. Based on long-term setup of the apparatus, the hot flow passes through the tube and the cold flow passes through the shell. Different configuration of valves can result in parallel and counter flows. The hot and cold flow rates are measured by two flow meters, located along the incoming flows. In order to measure the temperature of fluids and heat transfer surfaces, four thermocouples have been installed in this apparatus. The measured temperature of each thermocouple is shown on the readout when the selector switch points to the thermocouple number. The thermocouples are located in different positions to measure the temperature.

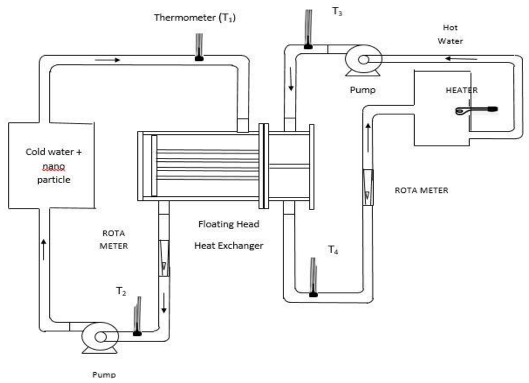

Fig. 1: Schematic Diagram of Floating Head Heat Exchanger with Nano Fluid.

2.5 Experimental Procedure

The Al_2O_3-water Nano fluids were prepared by adding several grams of Al_2O_3 nanoparticles to 800 ml of demineralized water. The amount of nanoparticle added depends on the required volume concentration. Four samples of Nano fluids were prepared. Initially the samples were mixed using ultrasonic bath, but due to ineffectiveness of the mixing process, mechanical stirrer was used. However using the stirrer did not provide a long period of stabilized dispersion of the nanoparticles. Hence, surfactant was added to the mixture, about 2% mass fraction of Sodium Lauryl Sulphate powder (SLS). The sample was then mixed using the stirrer for four hours.

To provide a basis for comparison, experiments were conducted to evaluate heat transfer performance of water as the coolant in the test rig. 800 ml of water was circulated in the test rig for four hours at the required operating temperature of 40°C. The flow rate for these experiments was set at 1.5 LPM as to emulate laminar flow condition.

The Al_2O_3-water Nano fluids which have been prepared earlier were pumped into the test rig. It was then heated and circulated under the fluorite of 1.5 LPM (under laminar condition) at the required operating temperature for the duration of four hours. Since there were four samples of Nano fluids, four experiments were conducted. For all the experiments, the operating temperature was set at 40°C.

3. FORMULATIONS

The effective thermal conductivity for a two-phase mixture consisting of a continuous and discontinuous phase has been conducted by Maxwell and the effective thermal conductivity K_{eff} is given by

$$K_{eff\ Maxwell} = \frac{2K_2+K_1+\emptyset(K_2-K_1)}{2K_2+K_1-2\emptyset(K_2-K_1)}K_1 \qquad (1)$$

Where K_1 and K_2 are thermal conductivity of the liquid and the particle respectively and / is the particle volume fraction Hamilton and Crosser extended Maxwell work to cover none spherical particles and introduced the shape factor (n) which can be determined experimentally for different type of materials. The goal of their research was to develop a model as a function of particle shape, composition and the conductivity of both continuous and discontinuous phases. Hamilton and Crosser model for a discontinuous phase (particles) dispersed in a continuous phase is:

$$K_{eff} = K_1\left[\frac{k_2+(n-1)K_1-(n-1)\emptyset(k_1-k_2)}{k_2+(n-1)K_1-\emptyset(k_1-k_2)}\right] \qquad (2)$$

Density of aluminum oxide=3890kg/m^3
Specific heat of aluminum oxide =880 J/kgk

$$\text{Volume fraction} = \emptyset = \frac{(m/\rho)n}{\left(\frac{m}{\rho}\right)n+\left(\frac{m}{\rho}\right)w} \qquad (3)$$

Density and specific heat are given by Wang and Mujumdar

$$\text{Density: } \rho_{nf} = (1-\varphi)\,\rho_{bf} + \varphi\rho_{np} \qquad (4)$$

Heat capacitance is as follows:

$$Cp,nf = \frac{(1-\emptyset)*Cp,bf*\rho,bf+\emptyset*\rho np*Cp,np}{\rho nf} \qquad (5)$$

A heat exchanger can be designed by the LMTD when inlet and outlet conditions are specified. When the problem is to determine the inlet and outlet temperatures for a particular heat exchanger, the analysis is performed more easily by using a method based on effectiveness of the heat exchanger and number of transfer units (NTU).

The heat exchanger effectiveness is defined as the ratio of actual heat transfer to the maximum possible heat transfer.

$$\varepsilon = \frac{Actual\ heat\ tranfer}{Maximum\ possible\ Heat\ transfer} = \frac{\text{Qactual}}{Qmax}$$

The actual heat transfer rate Q can be determined by energy balance equation,

$$Q = m_h C_{ph}(t_{h,in} - t_{h,out}) \qquad (6)$$

The fluid capacity rate C:
$m_h c_{ph}$= c_h= hot fluid capacity rate
c_{min} = the minimum fluid capacity rate
c_{max}= the maximum fluid capacity rate
The effectiveness

$$\varepsilon = \frac{C_h(t_{h,in}-t_{h,out})}{C_{min}(t_{h,in}-t_{h,out})}. \qquad (7)$$

The governing equations for design problem are usually given as follows:

$$\text{Heat rate } Q = C_h(T_{h,in} - T_{h,out}) \qquad (8)$$

Where,
Q= heat duty of heat exchanger, W
C_h= specific heat of the hot fluid, J/kgK
T_{hi}= inlet temperature of the hot fluid, K
T_{ho}= outlet temperature of the hot fluid, K
T_{ci}=inlet temperature of the cold fluid, K
T_{co}= outlet temperature of the cold fluid, K
Log Mean temperature difference

$$\Delta T_m = \frac{(T_{hi}-T_{co})-(T_{ho}-T_{ci})}{\ln[(T_{hi}-T_{co})\div(T_{ho}-T_{ci})]} \qquad (9)$$

We can calculate overall heat transfer co-efficient from the following equation

$$Q = h_o A \Delta T_m$$

Where
Q= Net heat
A= Overall surface area
ΔT_m = Log mean temperature difference

4. RESULTS AND DISCUSSION

When 1% nanoparticles (AL_2O_3) was mixed with base fluid (H_2O) then volume fraction was changed and Density as well as specific heat were changed. Volume fraction was changed and Density as well as specific heat were changed with respect to change the percentage of Nano fluids.

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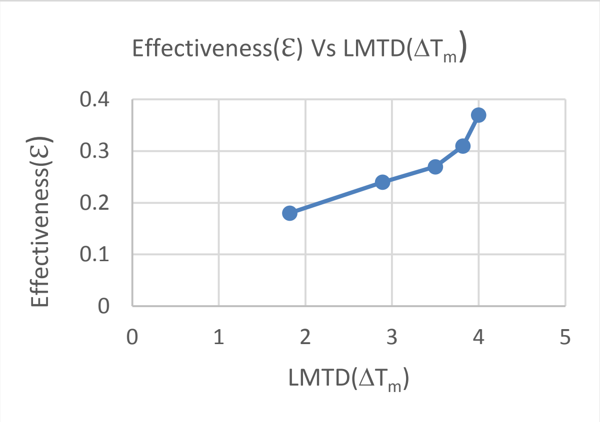

Fig. 2: Effect of Log Mean Temperature Difference on Effectiveness

As shown in Fig.2, the effect of log mean temperature difference on effectiveness, effectiveness of the floating head heat exchanger has increased with increase in log mean temperature difference because the larger the LMTD the more heat is transferred.

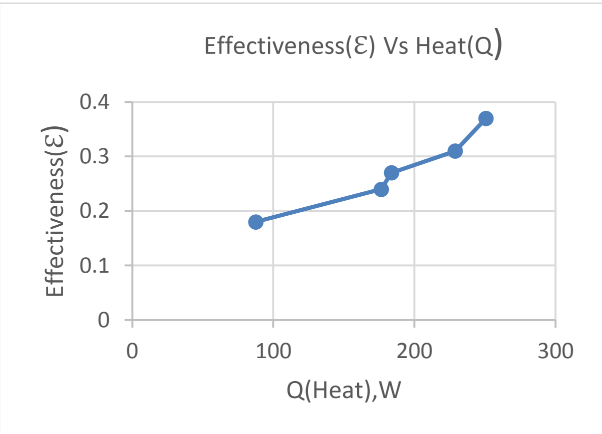

Fig. 3: Effect of heat transfer rate on effectiveness

Effectiveness also increases with the increase in heat energy of cold water and it is evident in the graph (Fig. 3) of effectiveness vs. heat transfer rate. Because there is a proportional relation between them. Comparison between Nano fluid and Conventional fluid (Water):

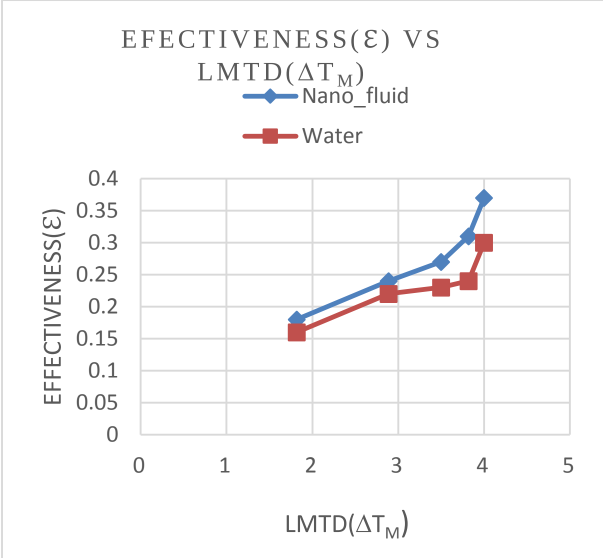

Fig. 4: Effect of LMTD(ΔT_m) on Effectiveness for Nano fluid and conventional fluid (water).

From (Fig. 4) Effect of LMTD(ΔT_m) on Effectiveness for Nano fluid and conventional fluid (water) it is seen that effectiveness of Nano fluid in heat exchanger is higher than effectiveness of conventional fluid (water) in heat exchanger.

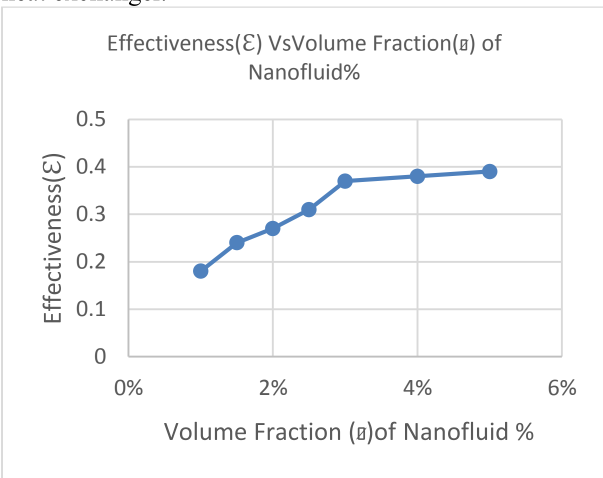

Fig. 5: Effect of Volume Fraction (ø) of Nano fluid % on Effectiveness

From (Fig. 5) Effect of Volume Fraction (ø) of Nano fluid % on Effectiveness it is noted that effectiveness of heat exchanger is increased with respect to increase Volume Fraction (ø) of Nano fluid %. Initially the rate of effectiveness is increased very quickly and gradually its rate is increased slowly. From (Fig. 6) it is seen that the overall heat transfer coefficient (h_0) is increased with increase of volume fraction of nanofluid (Al_2O_3). It is noted that the overall heat transfer coefficient (h_0) is increased with increase of volume flow rate of nanofluid (Al_2O_3). Top line in (Fig.6) indicates the overall heat transfer coefficient (h_0) when the flow rate of nanofluid (Al_2O_3) is 12.5 liter per minute. Top second line in (Figure 12) indicates the overall heat transfer coefficient (h_0) when the flow rate of nanofluid (Al_2O_3) is 11.5 liter per minute. Top third line in (Fig. 6) indicates the overall heat transfer coefficient (h_0) when the flow rate of nanofluid (Al_2O_3) is 9.5 liter per minute. Bottom line in

(Fig 6) indicates the overall heat transfer coefficient (h_0) when the flow rate of nanofluid (Al_2O_3) is 7.5 liter per minute.

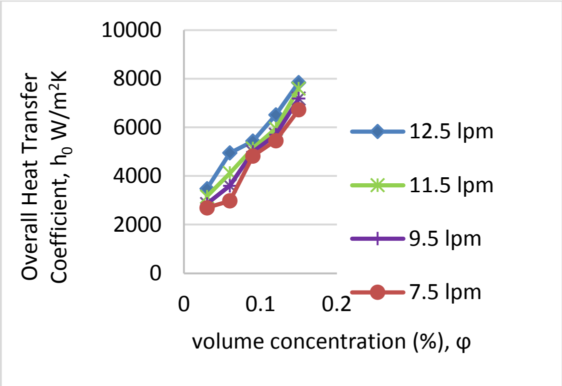

Fig. 6: Effect of volume concentration on Overall heat transfer coefficient at different flow rates.

The cost of titanium oxide (TiO_2) is very higher than the cost of aluminum oxide (Al_2O_3). Aluminum oxide (Al_2O_3) is more available than titanium oxide (TiO_2). the floating head heat exchanger with Nanofluid (Al_2O_3+water) can be used in nuclear power plant, medical science, oil refinery industries, refrigeration & air conditioning systems and for domestic purposes instead of the floating head heat exchanger with Nanofluid (TiO_2+water).

5. CONCLUSIONS

This project was started with an idea to increase the heat transfer rate of the heat exchanger using nanofluid (Al_2O_3). The experimental results showed that nanofluid (Al_2O_3) significantly improved the heat transfer capability of conventional heat transfer fluids such as oil or water by suspending nanoparticles (Al_2O_3) in the base fluid (water). Nanofluid (Al_2O_3) has a wide range of heat transfer applications. Several factors such as volume fraction, flow rate and temperature range etc. increased the effective thermal conductivity of the nanofluid. The experimental results indicate that thermal conductivity and viscosity was increased with an increase in the concentration of the nanofluid. Experiments have been conducted with nanofluid (Al_2O_3) at various concentrations and temperature ranges, for the estimation of the heat transfer coefficient, specific heat and friction factor for water-based nanofluid (Al_2O_3). All the experimental results confirmed enhancement of the heat transfer coefficient with an increase in concentration. The results of experiment have been also compared with other nanofluid (TiO_2) at the same condition. The experimental results are very close to the numerical results of the nanofluid (Al_2O_3). Effectiveness of floating head heat exchanger with nanofluid (Al_2O_3) also has been compared with effectiveness of floating head heat exchanger with normal water. As Nano fluids greatly increase the heat transfer coefficient of base liquid, compared to the defect taken by the volume of nanoparticle, its high heat transfer coefficient would bring more advantages. So increasing appropriately the particle volume fraction would be beneficial to the enhancement of heat transfer.

6. ACKOWLEDGEMENT

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