International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Special Issue - AMET-2019

Experimental investigation on heat transfer enhancement in shell and tube heat exchanger under forced convection using wire coil insert with magnetic nanofluid.

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Abstract - **In the present study, enhancement of Fe_3O_4 magnetic nanoparticles inside a horizontal shell and tube heat exchanger under laminar, transient and turbulent flow with three different heat fluxes to be investigated. For this purpose, Fe_3O_4 magnetic nanoparticles with less than 50 nm diameter and distilled water as base fluid to be used. The primary aim is to evaluate the effect of different weight concentration and temperatures on convective heat transfer. Increasing the weight concentration and temperatures leads to enhancement of convective heat transfer coefficient. The convective heat transfer of magnetic nanofluid with two concentrations 0.1 and 0.2 wt. % to be measured under different flows (Laminar, Transient and Turbulent) in a horizontal shell and tube heat exchanger. The heat transfer coefficient obtained with Fe_3O_4 magnetic nanofluid to be compared with the base fluid for different flows and weight concentrations.**

Keywords — Convective heat transfer coefficient, Enhancement, Fe_3O_4 Nanoparticles, Heat exchanger, Nanofluid

I. INTRODUCTION

Nanofluids constitute a mixture of nanometer sized solid particles and base fluid. In general, base fluids like water, ethylene glycol, engine oil etc. are used for dispersing the nanoparticles [1]. Due to restrictions of their thermal properties, traditional fluids such as water, engine oil, and ethylene glycol are inadequate for high heat flux application. Some nanofluid, made of nanoparticles and a based liquid, have been attracting much attention for they can improve the convective heat transfer and thermal conductivity of the based liquids [2, 3]. Some nanomaterial's, such as Cu, Fe, TiO_2, Al_2O_3, CuO, SiO_2, and carbon tube as a main ingredient of nanofluid, have been investigated [4, 5]. Wen and Ding and Lai et al. confirmed that the heat transfer coefficient of nanofluid is increased with flow rate and nanoparticle volume fraction [3, 6]. Anoop et al. demonstrated that the heat transfer coefficient of nanofluid is enhanced with the decrease of size of nanoparticles [8]. Heris et al. found that heat transfer coefficient of nanofluid were obvious difference different with kind of nanoparticles

II. EXPERIMENTAL PROCEDURE

A. Material and Nanoparticle synthesis.

Chemicals like $FeCl_3{\cdot}6H_2O$ (ferric chloride), $FeCl_2{\cdot}4H_2O$ (ferrous chloride) and NaOH (sodium hydroxide) were purchased from Sigma-Aldrich Chemicals. Magnetic Fe_3O_4 nanoparticles were synthesized by using the chemical co-precipitation method. The method follows: molar ratio of 2:1 of ferric chloride and ferrous chloride dissolved in 20 ml of distilled water in a beaker under magnetic stirring. The solution becomes orange in color, once the iron salts are fully dissolved in distilled water. Adjust the orange color solution pH equal to 12 by adding drop by drop of aqueous NaOH solution. During the addition of NaOH solution, the orange colored solution turns into black color and stir the solution continuously up to 45 minute precipitate was then filtered with filter paper and washed several times with distilled water and acetone for removing impurities. The Precipitate is dried in the oven at 80℃ for 24 h.

B. Nanofluid Preparation

Nanofluid is prepared by direct mixing of nanoparticles in the base fluid. In this analysis base fluid is a mixture of ethylene glycol and water. For a given percentage of volume concentration, the required quantity of nanoparticles was estimated from Eq. (1) [10]. Nanofluid samples were prepared by taking 50 ml of base fluid in a beaker and then directly added the required quantity of nanoparticles and kept the mixture in an ultrasonic bath up to 2 h. No surfactant was added to the solution. The prepared nanofluid is in very good condition up to two months.

$$\varphi \times 100 = \frac{\frac{W_{Fe3O4}}{\rho_{Fe3O4}}}{\frac{W_{Fe3O4}}{\rho_{Fe3O4}} + \frac{W_{bf}}{\rho_{bf}}} \qquad (1)$$

Where φ is percentage of volume concentration, ρ_{FeO4} is the density =5810 kg/m^3, W_{bf} is the weight of base fluid = 50 g, W_{Fe3O4} is the weight of nanoparticles, ρ_{bf} is the density of base fluid obtained from the ASHRAE [9] handbook, for 20:80% EG/W = 1026.02 kg/m^3.

C. *Experimental Setup*

An experimental test setup is fabricated to investigate the heat transfer coefficient and friction factor behavior of fluid in a shell and tube heat exchanger subjected to constant heat flux boundary condition. The schematic diagram and photograph of the experimental setup is shown in Fig.1 The hot fluid is stored in the hot fluid storage tank and heated with the help of heater there itself. The hot fluid then circulated by using pump and it pass through the tube inlet

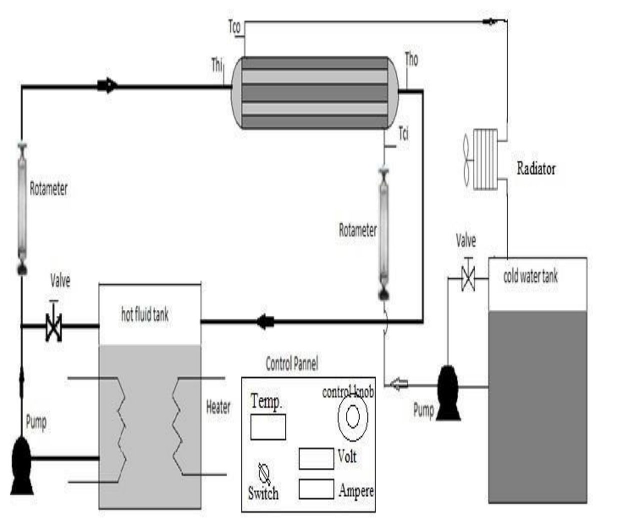

Fig. 3.1 General Arrangement of Experimental setup

and tubes of heat exchanger. The hot fluid then again circulated to the hot fluid storage tank. The pipes used for circulation of hot fluid are insulated to avoid the heat loss which occur during the circulation of the fluid. The hot fluid used for experimentation is Nanofluid ($_{Fe3O4}$ $_{+}$water + ethylene glycol) and base fluid mixture water and ethylene glycol of 80 % - 20 % proportion. The cold fluid is passed through the shell of the heat exchanger. The flow arrangement is kept counter flow. The water circulated by means of pump. The heated water then passed through the radiator for cooling it down to initial inlet fluid temperature. The outer surface of the test section is insulated by using foam material for minimizing the heat loss. Four K type thermocouples are used for the measurement of the inlet and outlet temperature of the hot fluid and inlet and outlet temperature of cold fluid. The thermocouples are inserted into the taps which are provided at inlet and outlet connection of the test section. These taps are then sealed by wax to avoid the leakage of the fluid.

The aspect ratio of the test section is sufficiently large so the flow is hydro dynamically developed. One end of the manometer is connected with the inlet tap, and the other end of the monometer is connected with the outlet tap. The readings of the level in the U-tube are noted down and made equal. Control panel controls the voltage and current inputs of heater and provide the digital output of temperature. The fluid line connections are checked for leaks after filling the storage tank with the working fluid. The Reynolds number of flow of the working fluid flowing in the test section is measured from the mass flow rate. All the heat transfer tests and friction factor tests are conducted in the flow Reynolds number. Total data points are generated for the estimation of overall heat transfer coefficient and friction factor with inserts.

III. DATA REDUCTION

$$\rho_{nanofluid} = (1-\varphi)\rho_{bf} + \varphi\rho_{Fe3O4} \qquad (2)$$

$$C_{nanofluid} = (1-\varphi)C_{bf} + \varphi C_{Fe3O4} \qquad (3)$$

Wasp [10] model is considered for the estimation of thermal conductivity

c

Brickman viscosity correlation as it applies to concentrated particle suspension

$$\mu_{nanofluid} = \mu_{bf}\left(\frac{1}{(1+\varphi)^{2.5}}\right) \qquad (5)$$

$$Q_h = m_h \times Cp_h \times (Th_i - Th_o) \qquad (6)$$

$$Q_c = m_c \times Cp_c \times (Tc_i - Tc_o) \qquad (7)$$

Where,

Q_h is heat transfer by hot fluid.

$Q_{c\ is}$ heat received by cold fluid.

m_h is mass flow rate of hot fluid.

m_c is mass flow rate of cold fluid.

T_{hi} & T_{ho} are the inlet and outlet temperature of hot fluid respectively.

$T_{ci\ \&}$ T_{co} are the inlet and outlet temperature of cold fluid respectively.

C_h & C_c are the specific heats of hot and cold fluid respectively.

IV. RESULT AND DISCUSSION

Experiments where conducted with base fluid (mixture of water and ethylenen glycol).It can be observed from figure 2 that heat transfer coffiecient increases with increase in Reynolds number.This implies that increase of heat transfer coffiecient with increase in mass flow rate. It can be observed from figure 3 that Nusselt number increases with increase in Reynolds number.It can be observed from figure 4 that friction factor decreases with increase in Reynolds number as flow rate increases means an increase in velocity as well.

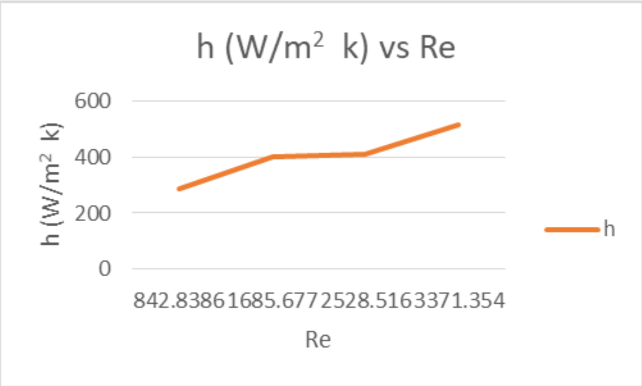

Figure.2. Effect of Reynolds number variation on Heat Transfer Coefficient

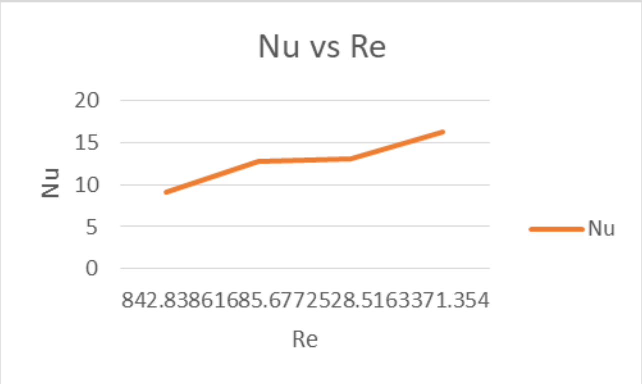

Figure.3. Effect of Reynolds number variation on Nusselt number.

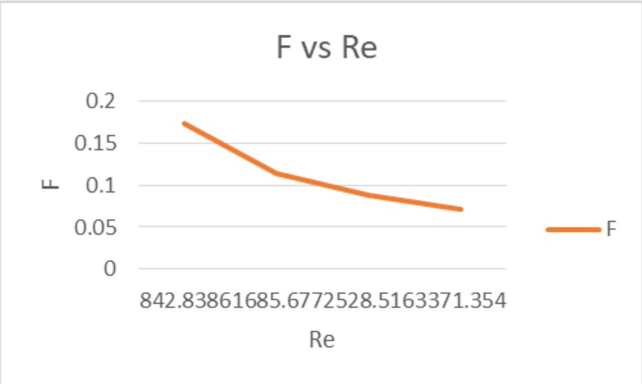

Figure.5. Effect of Reynolds number variation on Friction Factor.

V. CONCLUSION

A detailed investigation of convective heat transfer behavior of magnetic nanofluid in shell and tube heat exchanger to be carried out. For Nanofluid with particle size less than 50 nm and base fluid of water as well as ethylene glycol is to be prepared, stabilized, and characterized with help of TEM. Numerical analysis to be performed for heat exchanger using software for validation purpose. Synthesis of Nano fluid to be done. Comparison of experimental and numerical results to be carried out.

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