International Journal of Scientific Engineering and Technology ISSN:2277-1581
Volume No.6 Issue No.2, pp: 75-79 01 Feb. 2017

Experimental Analysis on Annular Disc Heat Exchanger with Nano Fluids

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Abstract : In the present study a double pipe heat exchanger is fabricated with flow path modification in the annulus. The influence of nanoparticles on thermo-physical properties of the working fluid is evaluated using established correlations available in literature. The combined influence of copper oxide nanofluid on heat transfer is evaluated for two different volume concentrations of nanofluid. Two different volume concentrations of copper oxide nanofluid is prepared with water as the base fluid. The thermophysical properties are evaluated with established correlations available in literature. The fabricated test section is initially validated with water as the working fluid later experimentation is carried out using prepared two different volume concentrations of copper oxide nanofluid independently.

Keywords : Copper oxide nanofluid, thermo physical properties, forced convection

I.INTRODUCTION

Heat exchangers are devices used to transfer heat between two or more fluid stream sat different temperatures. Heat exchangers find widespread use in power generation, chemical processing, electronics cooling, air-conditioning, refrigeration, and automotive applications. The heat exchanger is a thermal heat transfer device that exchanges the thermal energy from one source and transfers it to another at different temperatures. zHosniAbu-Mulaweh [i] presents an experimental comparison between four different types of heat transfer enhancement techniques or methods in heat exchangers: Two insert devices(displacement device and swirl flow device), extended surfaces, and obstruction devices. The heat exchanger is a simple, double-pipe heat exchanger. They measure the temperatures of the hot water, the cold water, and the copper tube. These measurements are necessary to determine the log mean temperature difference (LMTD). K.V.Sharma et al., [ii] studied the properties of nanofluids from various sources available in the literature are correlated with reasonable accuracy considering nanofluid as a homogenous medium. These correlations are subsequently employed in the evaluation of momentum and convective heat transfer coefficients for turbulent flow in a tube. Regression techniques are used to establish correlations, to predict friction and heat transfer coefficients for a wide range of nanofluids containing Cu, CuO, TiO_2, SiC, $ZrO_2$and Al_2O_3 nanoparticles of different sizes, concentration and temperatures dispersed in water. K.Sivakumar et al., [iii] done investigation on the heat transfer and effectiveness of the double pipe heat exchanger with two flow directions; one is parallel flow and counter flow direction.. In the present study, the heat transfer and friction factor of plain tube fitted with laminar flow conditions were simulated using Ansys fluent version. Deepali Gaikwadet al.,[iv] done Thermal Performance of heat transfer devices by heat transfer enhancement techniques. In the present study, heat transfer from hot water to cold water by double pipe heat exchanger for plain tube and plain tube with twisted wire brush inserts is experimentally investigated. Based on the experimental results the Nusselt number obtained for the tube with twisted wire brush inserts varied from 1.55 to 2.35 times in comparison to those of the plain tube. N. Targuiet al., [v] worked on the numerical simulation of nanofluids flow in a double pipe heat exchanger provided with porous baffles. The hot nanofluid flows in the inner cylinder, whereas the cold nanofluid circulates in the annular gap. The Darcy- Brinkman-Forchheimer model is adopted to describe the flow in the porous regions, and the governing equations with the appropriate boundary conditions are solved by the finite volume method. The results reveal that the addition of metallic nanoparticles enhances the rate of heat transfer in comparison to conventional fluids but this augmentation is accompanied by an increase in pressure drop. The highest heat exchanger performances are obtained when nanoparticles are added only to the cold fluid.

II.PREPARATION OF NANOFLUID

The idea behind development of nanofluids is to use them as thermo fluids in heat exchangers for enhancement of heat transfer coefficient and thus to minimize the size of heat transfer equipment. Nanofluids help in conserving heat energy and heat exchanger material. The important parameters which influence the heat transfer characteristics of nanofluids are its properties which include thermal conductivity, viscosity, specific heat and density. Thermo physical properties of nanofluids are prerequisites for estimation of heat transfer coefficient and the Nusselt number.

Nanofluid preparation using CuO nanoparticles

The CuOnano particles having an average size of 40 nm and density of 6.4gm/cc is procured from a Indian based company (Nano labs Private Ltd) and is used for investigation in the present experimental work. The distilled water was used as a base fluid for this study. The nanofluids of different volume concentrations were prepared by dispersing different quantity of CuO nanoparticles in distilled water. The solution was sonicated continuously for 1hour using a probe sonicator to disperse the nanoparticle uniformly.Following this, the nanofluid was stirred continuously for 18-20 hours by adding

0.05% of Oleic acid in order to obtain uniform dispersion of nanoparticles in base fluid. Here, the oleic acid acts as a surfactant.

Fig.2.1Nanofluid preparation using ultrasonicator and Magnetic stirrer

III.EXPERIMENTAL SETUP AND PROCEDURE

The Experimental setup consists of the following components DC Water pump, Sump, Heating Coil, Connecting Pipes, Power Supply Unit, Digital Temperature Indicator, Test specimen

Test specimen

The heat exchanger is a simple double pipe heat exchanger of length 400mm.The inner tube is copper of inside diameter 13.8 mm and outside diameter 15.8mm. The outer tube is a mild steel pipe with an inside diameter of 38mm and outside diameter of 42mm. The problem is then how to install and support the annular disks inside the mild steel pipe. The method that was choosen was to make the disk an integral part of thin walled tube that slipped inside the mild steel pipe. To do this, seven annular disks were made and installed. The end result was a tube of 400mm long, disks having a1.5mm opening space on 50mm centers along the tube.

Experimental procedure

All the connections are made according to the circuit diagram. At first double pipe heat exchanger is validated with distilled water at different power inputs. The sump is filled with 1000 ml of distilled water and the outlet is connected to the pump and then it is flown into the test section and finally returns to the sump and then the fluid is recirculated.

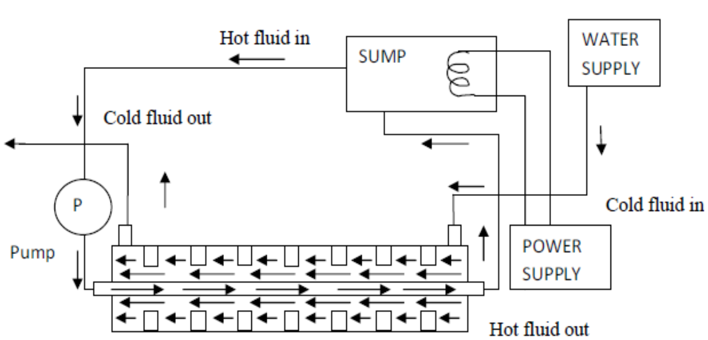


Fig.3.1 Schematic representation of experimental set up

But the continuous supply of cold fluid is given in the counter flow direction from overhead water tank. Before starting the experiment the flow rate of cold fluid in the annular region and hot fluid in the inner region of the pipe are measured by collecting 1000ml of fluid in a measuring jar. The schematic diagram of the above experimental setup is as shown in the Fig.3.1.Initially 20watt input power is given to the heating coil by regulating the dimmerstat and reading of ammeter and voltmeter are recorded. The temperature of the hot fluid at the inlet, outlet and surface temperature of the test section are measured with the helpof digital temperature indicator for every 10 minutes. Simultaneously the reading at the cold fluid inlet and outlet are measured .The reading are noted until the steady state condition reaches. An increment of 20watt input is given to heating coil upto 260watt and the process is repeated. All the steady state readings of all the inputs are tabulated. Using the above tabulated data the inside heat transfer coefficient and Nusselt number of the inside fluid are calculated using the correlation discussed earlier.

Fig.3.2 Experimental setup of heat exchangers with Annular disc

The distilled water is replaced with the CuO nanofluid of two volume concentrations (ϕ=0.05 % and ϕ=0.1%)and the experimental procedure is repeated both for double pipe heat exchanger and annular discs then the steady state reading are tabulated.

Experimental correlations

The density of the base fluid distilled water and nanofluid was calculated by using eqn 1&2 respectively.

$$\rho_w = 1000 \times \left[1.0 - \frac{(T_b - 4.0)^2}{119000 + 1365 \times T_b - 4 \times (T_b)^2}\right] \quad (1)$$

$$\rho_{nf} = \phi\rho_p + (1 - \phi)\rho_w \quad (2)$$

The Thermal conductivity of the base fluid distilled water and nanofluid was calculated by using eqn 3&4 respectively.

$$k_w = 0.56112 + 0.00193 \times T_b - 2.60152749\text{e}{-6} \times (T_b)^2 - 6.08803\text{e}{-8} \times (T_b)^3 \quad (3)$$

$$k_{nf} = k_w \times 0.8938\left[1+\frac{\phi}{100}\right]^{1.37}\left[1+\frac{T_{nf}}{70}\right]^{0.2777}\left[1+\frac{d_p}{150}\right]^{-0.0336}\left[\frac{\alpha_p}{\alpha_w}\right]^{0.01737} \quad (4)$$

The dynamic viscosity of the base fluid distilled water and nanofluid was calculated by using eqn 5&6 respectively.

$$\mu_w = 0.00169 - 4.25263e-5 \times T_w + 4.9255e-7 \times (T_b)^2 \;\; 2.0993504e-9 \times (T_b)^3 \quad (5)$$

$$\mu_{nf} = \mu_w\left[1+\frac{\phi}{100}\right]^{11.3}\left[1+\frac{T_{nf}}{70}\right]^{-0.038}\left[1+\frac{d_p}{170}\right]^{-0.061} \quad (6)$$

The friction factor of the base fluid distilled water and nanofluid was calculated by using eqn 7&8 respectively.

$$f_b = {0.3164}/{Re^{0.25}} \quad (7)$$

$$f_{nf} = f_b \times 1.078\left[\frac{\mu_{nf}}{\mu_w}\right]^{-0.1248}\left[\frac{\rho_{nf}}{\rho_w}\right]^{-0.5144} \quad (8)$$

The rate of heat transfer and heat flux was calculated by using eqn 9&10

$$Q = \dot{m}\, C_p (T_{hi} - T_{ho}) \quad (9)$$

$$q = Q/A \quad (10)$$

The overall heat transfer coefficient was calculated by the eqn 11

$$q = U\left[T_b - \frac{T_{ci}+T_{co}}{2}\right] \quad (11)$$

The outside and inside tube heat transfer coefficient was calculated by using eqn 12&13 respectively.

$$h_o = \frac{q}{\left[T_s - \frac{T_{ci}+T_{co}}{2}\right]} \quad (12)$$

$$1/h_i = 1/U - 1/h_o \quad (13)$$

Nusselt number was calculated by using the eqn 14

$$Nu_{exp} = (h_i \times d_i)/k_w \quad (14)$$

Dittus Boelters equation

$$Nu_{Theoretical} = 0.023(Re_D)^{0.8} \times (Pr)^{0.4} \quad (15)$$

IV.RESULTS AND DISCUSSIONS

The fabricated test section was initially validated using water as the working fluid flowing through a double pipe heat exchanger. The inlet and exit temperatures were recorded for a definite mass flow rate. The data was further used to determine to estimate Reynolds number, Prandtl number and Nusselt number

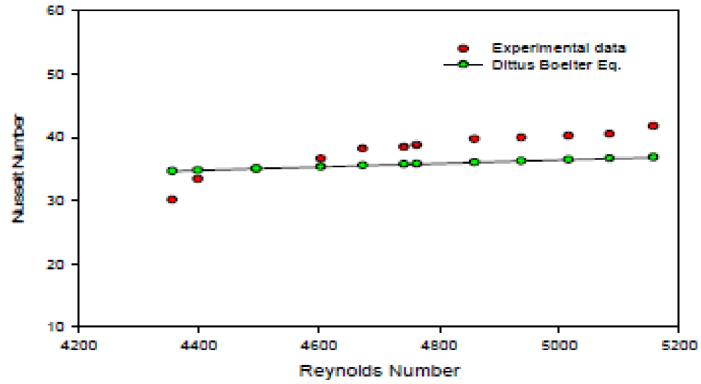


Fig.4.1 Validation of experimental set up

The experimental data of base fluid water was found to be in close agreement with established Dittus Boelter equation, the experimental set up is further used to analyze the influence of nano particles at different volume concentration in the base fluid distilled.

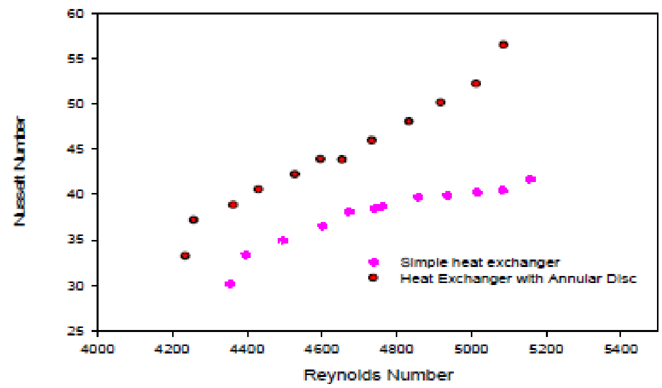


Fig.4.2 Variation of Nusselt number with and without annular disc

The experimental procedure is repeated for same mass flow rates and heat inputs with water as working fluid with annular disc in the annulus. The recorded data is further used to estimate Nusselt number and Reynolds number to study the influence of annular disc in the annulus. The Nusselt number is found to increase 18.30% proportionately under the influence of annular disc as shown in Fig. 4.2, certainly indicating the presence of annular disc enhances the rate of heat transfer across the test section.

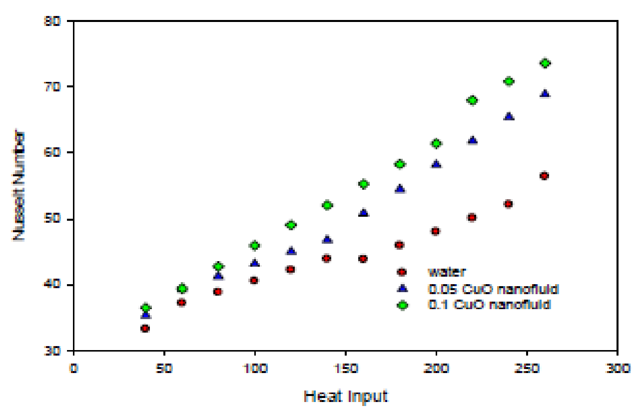


Fig.4.3 Variation of Nusselt number with heat input

The Experiment were conducted within a range of heat inputs from20W to 260W with an increment of 20W. Three sets of experiments were conducted, each for base fluid (distilled water) followed by two different volume concentrations of copper oxide namely 0.05 and 0.1 respectively dispersed in base fluid water. The presence of copper oxide nanoparticle improves heat transfer coefficient as compared to base fluid distilledwater as seen in Fig.4.3 It is further found that Nusselt number is found to increase with increasing volume concentration of nanoparticle in the base fluid.

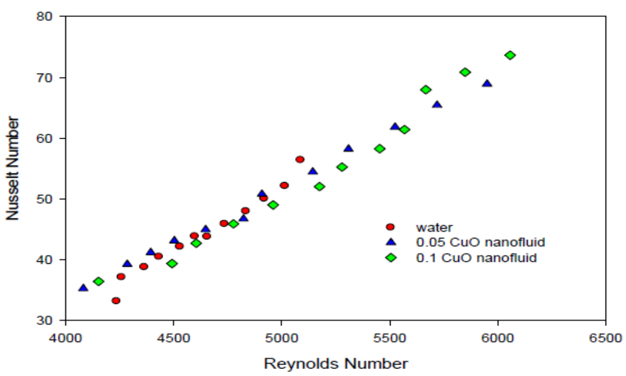


Fig.4.4 Variation of Nusselt number with Reynolds number

The influence of copper oxide nanoparticle on heat transfer is presented in Fig. 4.4. There has been a significant improvement in Reynolds number under the influence of nanoparticles as compared to distilled water. Thermo-physical properties of nanofluids contributes a larger share like 12.47% improvement in thermal conductivity which increases with increasing volume concentration of nanoparticles and 10.82% reduction in dynamic viscosity with increasing temperature contributes to increase in Nusselt number with increasing heat flux certainly enhancing the heat transfer coefficients under the presence of nanoparticles in the water. An improvement of 15.26% is observed with 0.05 volume concentration of CuO nanofluid and 24.92%improvement is observed with 0.1 volume concentration nanofluid as compared to water.

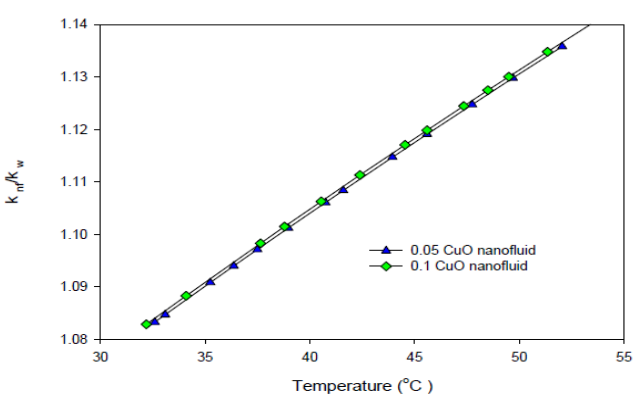
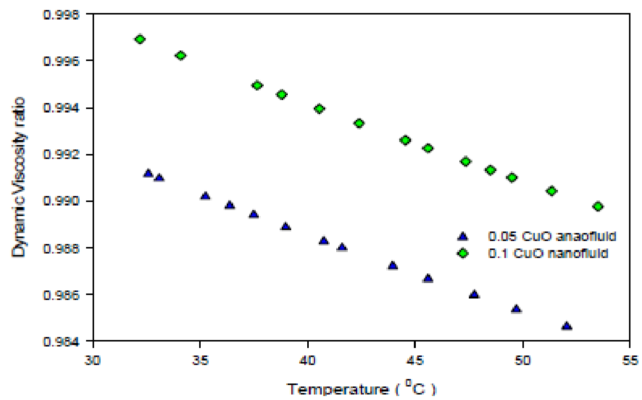


Fig.4.5 Variation of thermal conductivity with temperature

The thermal conductivity of nanofluid is found to increase with increasing volumeconcentration of nanoparticle in the base fluid and temperature. The presence of nano particle in the base fluid water could lead to improved effective thermal conductivity of nanofluid possibly due to increased surface area of suspended nanoparticle and Brownian motion of dispersed particles in the base fluid which contributes to enhanced thermal conductivity of nanofluid. The variation of thermal conductivity for various concentrations of nanofluid and at different temperatures is shown in Fig 4.5



Fig,4.6 Variation of dynamic viscosity with temperature

The dynamic viscosity of nanofluid is found to vary with the temperature and the volume concentration of nano particle in the base fluid. The dynamic viscosity increases with the increase in the volume concentration of nanoparticle and decreases with the increase in temperature. The variation of dynamic viscosity with respect to temperatures and concentration of nanoparticle is shown in Fig 4.6

Formulation of new regression equation

$$Nu_{Regression} = 0.3217\times10^{-5}(Re)^{2.233}(Pr)^{0.1387}(1-\phi)^{0.3151}(f/8)^{0.4910}$$

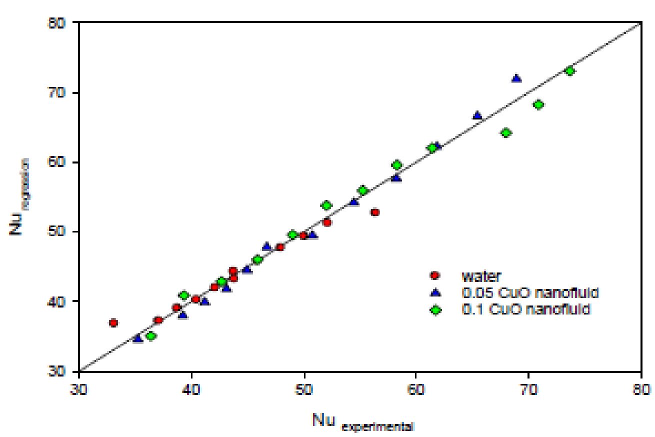


Fig.4.7 Experimental Nusselt vs Regression Nusselt number

The experimental data indicates an improvement in heat transfer with increasing volume concentration of nanoparticles in distilled water, a general regression equation is formulated for Nusselt number as a function of Reynolds number, Prandtl number, volume fraction and friction factor. A Force program is used to formulate a regression equation with an average deviation of 2.18% and standard deviation of 3.16%.

V.CONCLUSION

In the present experimental work,a modified heat exchanger with annular disc in the annulus is fabricated and two different volume concentration of copper oxide nanofluid is used in the analysis. The influence of nanoparticle on thermo-physical properties and on heat transfer is analysed and presented in the subsequent sections.

a) Two different copper oxide nanofluid were prepared with 0.05% by volume surfactant (oleic acid) was prepared and was found to be stable for 2 weeks.

b) The thermal conductivity of 0.05% and 0.1% volume concentration is found to increase by 11.18% and 12.47% respectively.

c) The dynamic viscosity of 0.05% and 0.1% volume concentration is found to decrease by 6.35 % and 10.82% respectively.

d) The evaluated Nusselt number from experimental data using fabricated experimental set up is found to be in close agreement with Ditus Boelter equation and hence it was extended for further investigation using nanofluids.

e) The influence of annular disc on heat transfer is found to increase by 18.30% with distilled water as working fluid.

f) The combined influence of annular disc and 0.05% volume Concentration is found to increase by 15.26%

g) The combined influence of annular disc and 0.1% volume Concentration is found to increase by 24.92%

Nomenclature

C Specific heat(J/kg^{0}K)
D diameter of the outer tube(m)
d diameter of the inner tube(m)
f friction factor
h heat transfer coefficient (W/m^2 ^{0}K)
k Thermal conductivity (W/m ^{0}K)
ṁ mass flow rate of the fluid (kg/s)
pr Prandtl number
Q rate of heat transfer (W)
q heat flux(W/m^2)
Re Reynolds number
T temperature (^{0}C)
U Overall heat transfer coefficient (W/m^2 ^{0}K)
W weight of the nanoparticle (grams)

Greek Symbols

α Thermal diffusivity (m^2/s)
ρ density (kg/m^3)
μ dynamic viscosity (Ns/m^2)
ϕ Volume concentration of nanoparticles (%)

Subcripts

b bulk mean temperature
bf base fluid
ci cold inlet
co cold outlet
hi hot inlet
ho hot outlet
i inside
o outside
nf nanofluid
p particle
w water

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