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EXPERIMENTAL INVESTIGATION OF RELATIVE PERFORMANCE OF WATER BASED TiO_2 AND ZnO NANOFLUIDS IN A DOUBLE PIPE HEAT EXCHANGER

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Abstract. This paper deals with experimental determination of convective heat transfer coefficient in a counter flow double pipe heat exchanger using water based TiO_2, ZnO nanofluids with 0.002% & 0.004% volume concentrations. Experiments are conducted at various Reynolds numbers ranging from 1600 to 6100. From the experimental results it is found that heat transfer coefficient increases with increase of volume concentration of nanoparticles as well as Reynolds number. Enhancement of heat transfer coefficient between nanofluids with 0.002% volume concentration of TiO_2, ZnO and the inner walls of copper tube in a double pipe heat exchanger increased up to 30.37% and 57.31% respectively. The enhancements are as high as 66.12% and 78.30% when the volume concentration is 0.004% of TiO_2 and ZnO respectively for same set of operating conditions when compared to pure water at Reynolds number 6100. The experimental results are presented in graphical form. The variation of heat transfer coefficient in both dimensional and non-dimensional form are presented as a function of Reynolds number for different volume concentrations of nanofluids. The effectiveness of heat exchanger is also presented as a function of volume concentration of nanofluids.

1. Introduction

Conventional liquids such as water and ethylene are commonly used coolants in a wide variety of heat exchangers to dissipate heat from electronic devices and automobiles to prevent overheating which might lead to failure. However, these convectional heat transfer fluids generally have poor thermal properties. Many experimental studies have been conducted by researchers on liquids containing micro metallic particles with high thermal conductivity with the aim of improving the thermal properties of the convectional heat transfer fluids. The use of micron sized course particles in liquids produces sedimentation and erosion of tube material. Hence the use of micron size particles is dispensed with and substituted by alternate nanoparticles. Choi [1] and his team developed nano-sized particles and achieved higher thermal conductivity by engineering the particle dispersion in liquids. Subsequently, the investigators like Masuda et al.[2], Lee et al.[3], Wang et al. [4], Eastman et al. [6], Das et al. [7] mostly concentrated on the determination of effective thermal conductivity of nanofluids.

Pak and Cho [8] studied the performance of Nano-fluids prepared using Al_2O_3 and TiO_2 nanoparticles dispersed in water flowing in a horizontal circular tube. Alumina (Al_2O_3) and titanium dioxide (TiO_2) nanoparticles with diameters of 13 nm and 27 nm, respectively, were used in their study. They found that the Nusselt number of nanofluids increased with an increase in the Reynolds number as well as the volume fraction of nano particles. However, they still found that the convective heat transfer coefficient of the nanofluids with 3 vol. % nanoparticles was 12% lower than that of pure water at a given Reynolds number. This may be due to the nanofluids to have larger viscosity than that of pure water, especially at high particle volume fractions. Finally, they arrived a new correlation for predicting the convective heat transfer coefficient of nanofluids in a turbulent flow regime.

He [9] reported the results of an experiment in which the heat transfer and flow behavior of TiO_2–distilled water nanofluid were reported when flowing in an upward direction through a vertical pipe in both the laminar and turbulent flow regimes under a constant heat flux boundary condition. The results showed that the convective heat transfer coefficient increased with an increase in nanoparticle concentration in both the laminar and turbulent flow regimes. Similarly, at a given nanoparticle concentration and Reynolds number, the heat transfer coefficient did not seem to be sensitive to the average particle size under the conditions of the experiment. The small effect of particle size on the heat transfer coefficient could be due to migration of the nanoparticles. The pressure drop in the nanofluids was approximately the same as that of the base fluid.

It can be noted that the experimental investigations found in the literature described above focused on the constant heat flux and the constant wall temperature boundary condition. The heat transfer and fluid flow characteristics of nanofluids in a double-pipe heat exchanger remain relatively unexplored. The earlier researchers estimated heat transfer coefficient of different volume concentrations of different kinds of nanofluid under laminar and turbulent flow condition. Therefore, this article is aimed at studying the heat transfer enhancement and flow characteristics of TiO_2+water and ZnO+water nanofluids at a low concentration flowing in a horizontal concentric tube-in-tube (double pipe) heat exchanger with various flow conditions. The main objective of the present investigation is to estimate the heat transfer coefficient of low volume concentration of TiO_2 and ZnO in a double pipe heat exchanger.

2. Preparation of nano fluids:

Estimation of weight of nanoparticles required for preparation of nanofluids with different volume concentrations is described below.

TiO_2 and ZnO nanoparticles with an average particle diameter of 21*nm* are purchased from Sigma Aldrich Chemicals Ltd., USA and these are dispersed in water for the preparation of nanofluids. The quantity of TiO_2 and ZnO nanoparticles required to prepare nano fluids with different volume concentrations can be calculated by using the following equation.

$$\text{Percentage of volume concentration} = \frac{\text{Volume of Nanoparticles}}{\text{Volume of Nanoparticles} + \text{Volume of water}} \quad (1)$$

Percentage of volume concentration = $\dfrac{\dfrac{W_p}{\rho_p}}{\dfrac{W_p}{\rho_p}+\dfrac{W_w}{\rho_w}}$ (2)

The density of TiO_2 (ρ_t) is 4260 kg/m^3. The density of ZnO (ρ_z) is 5610 kg/m^3. The density of water (ρ_w) is 993 kg/m^3 at atmospheric temperature. Substitute the above values in the equation (2) and whereas weight of water considered is 30 kg**.**

Percentage of volume concentration = $\dfrac{\dfrac{W_p}{\rho_p}}{\dfrac{W_p}{\rho_p}+\dfrac{3000}{\rho_w}}$ (3)

Table. 1 Sample Data

S. No.	**Volume Fraction, %**	**Weight of** TiO_2**, gms**	**Weight of** ZnO**, gms**
1	0.002	2.36	3.36
2	0.004	4.73	6.72

3. Preparation of TiO_2 nanofluid:

For preparation of Nano-fluids, generally, two methods are used.

(1) Mixing the nanoparticles directly with the basefluid.
(2) Adding surfactants to the base fluid initially and then adding nanoparticles.

Nanofluid is a combination of nanoparticles and base fluid. Initially nanoparticles are directly mixed with water as per the required percentage of volume concentration. It was observed that the particles are settling quickly at the bottom of the base fluid due to difference in the density. To circumvent the problem of particle settling, 0.5ml of oleic acid and CTAB (Cetyl Trimethyl Ammonium Bromide) to an extent of 1/10th of weight of TiO_2 is added to the base fluid prior to adding TiO_2 nanoparticles. The nanofluid thus prepared is kept in an ultrasonic bath for 6-8 hour in order to avoid the sedimentation. Using the above procedure two different samples with 0.002%, 0.004% concentration are prepared and these are used for the estimation of thermal conductivity of TiO_2 and ZnO water based nanofluids.

4. Experimental setup:

The schematic diagram of the experimental test setup is shown in Fig.1. The apparatus consists of a test section, two reservoir tanks, hot water pump and cold water pump. The test section is 1.5m long horizontal double pipe heat exchanger with nanofluid flowing inside the tube while the hot fluid flows in the annular space. The inner tube is made from smooth copper tubing with a 9.53mm outer diameter and 8.13mm inner diameter, while the outer tube is made from PVC tubing and has 33.9mm outer diameter and 27.8mm inner diameter. The test section is thermally isolated from the surroundings by asbestos rope insulation in order to reduce the heat loss to the atmosphere.

Thermocouples of type-J are mounted at both the ends of the test section to measure the bulk temperature of the nanofluid under consideration. The inlet and exit temperature of hot water is also measured using J-type thermocouples which are inserted into the flow directly. The receiver tanks are used for collecting the nanofluid and hot water leaving the test section. During the test run, the inlet and exit temperatures of the hot water and nanofluid are measured. The mass flow rate of both hot and cold fluids is measured using an inline fluid flow measuring device.

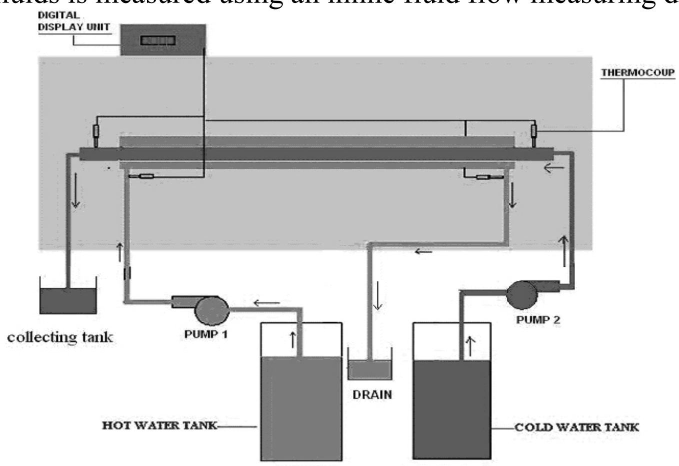

Fig. 1 Schematic diagram of the experimental setup

5. Data reduction:

The amount of heat gained by the cold fluid is estimated by using Eq. 1

$$Q_c = m_c Cp_c (T_{co} - T_{ci}) \quad (1)$$

Where

Mass flow rate, $m = \frac{\text{Re} * \pi * d_i * \mu}{4}$

Re = Reynolds number

d_i = diameter of inner tube

μ = viscosity of fluid

Cp = Specific heat in J/kg-K

From Newton's law of cooling

$$Q_c = h_i A (\Delta T)_{LMTD} \quad (2)$$

Where $(\Delta T)_{LMTD}$ = Logarithmic Mean Temperature Difference for counter flow.

$= (\Delta T_1 - \Delta T_2) / \ln(\Delta T_1 / \Delta T_2)$

$\Delta T_1 = T_{hi} - T_{co}$

$\Delta T_2 = T_{ho} - T_{ci}$

A =surface area of the inner copper tube = $\pi d_0 L$

Nusselt number,

$$Nu = \frac{h_i D}{k} \quad (3)$$

Experimental heat transfer coefficient and Nusselt number are estimated from Eq. 2 & Eq.3.

Effectiveness of Heat exchanger,

$$E = \frac{q}{q_{max.}}$$

$$q_{max.} = Cp_{min.}\left(T_{hi} - T_{ci}\right)$$

$$q_{.} = Cp_h\left(T_{hi} - T_{ho}\right) = Cp_c\left(T_{co} - T_{ci}\right)$$

Therefore, $$E = \frac{Cp_c(T_{co} - T_{ci})}{Cp_h(T_{hi} - T_{ci})}$$

6. Results and Discussions:

Initially proving experiments are conducted with water to establish the validity of the experimental results as a part of calibration process. The deviation between the energy gained by the nanofluid from the energy lost by the hot fluid is in the range of less than 5%. After validating the results obtained from the test setup using water as heat transfer fluid, nanofluid at different volume concentration are introduced into the test section for the estimation of heat transfer coefficient. The wall temperature and bulk mean temperature of water and nanofluids of TiO_2 and ZnO with different volume concentrations and Reynolds numbers are shown in Fig. 2. From the figure it is evident that the wall temperatures decrease from 80^0C and bulk mean temperature increases from 35^0C.

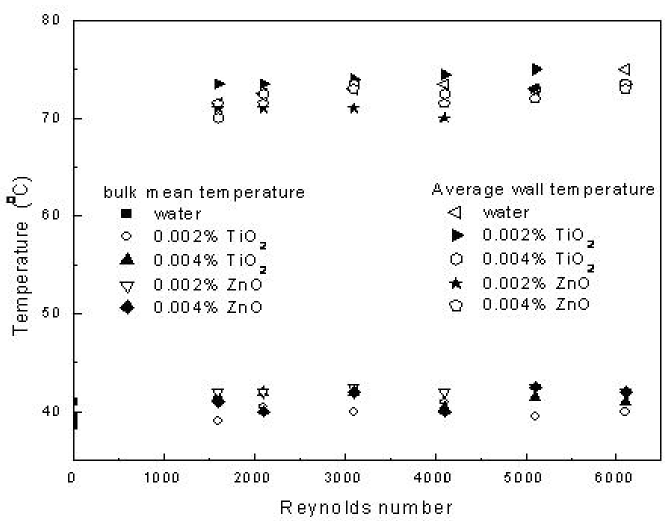

Fig. 2 Variation of bulk mean temperature of wtaer and wall temperature as a function of different volume concentrations of nanofluid.

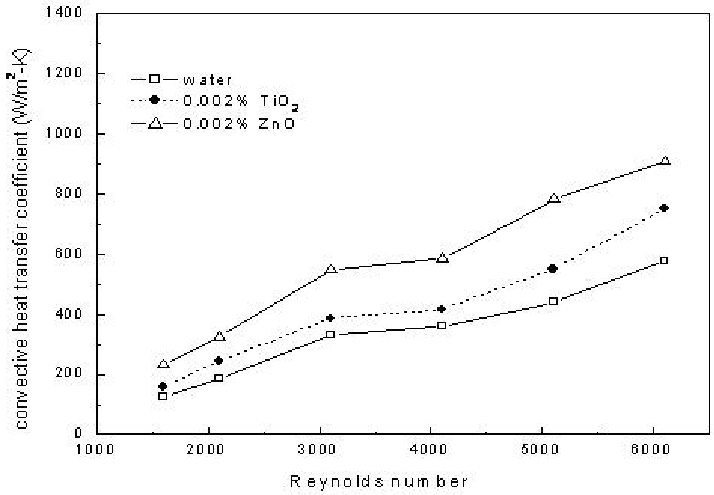

Fig. 3 Convective heat transfer coefficient as a function of Reynolds numbers at 0.002% concentration for nanofluids.

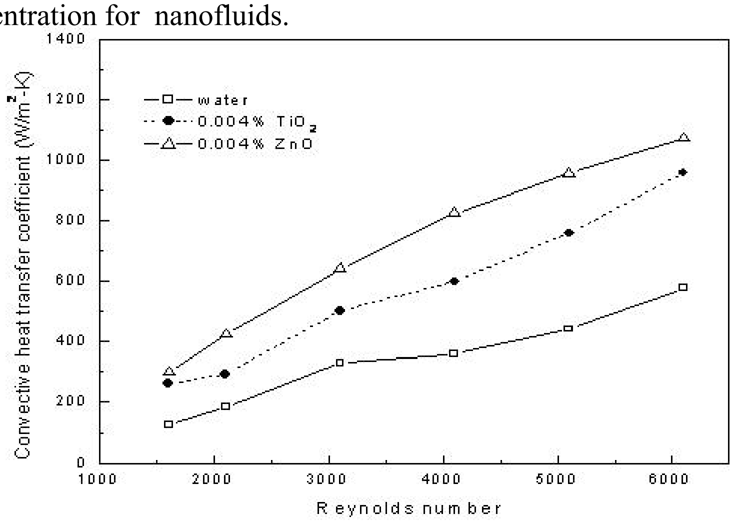

Fig. 4 Convective heat transfer coefficient as a function of Reynolds numbers at 0.004% concentration for different nanofluids.

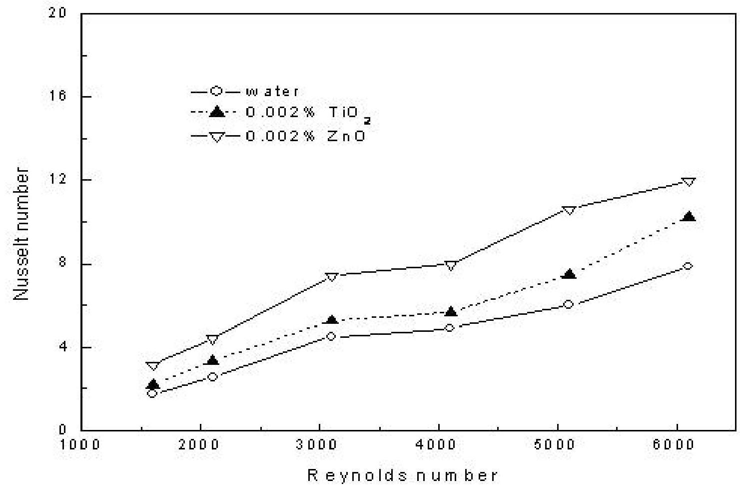

Fig. 5 Nusselt number as a function of Reynolds numbers at 0.002% concentration for different nanofluids.

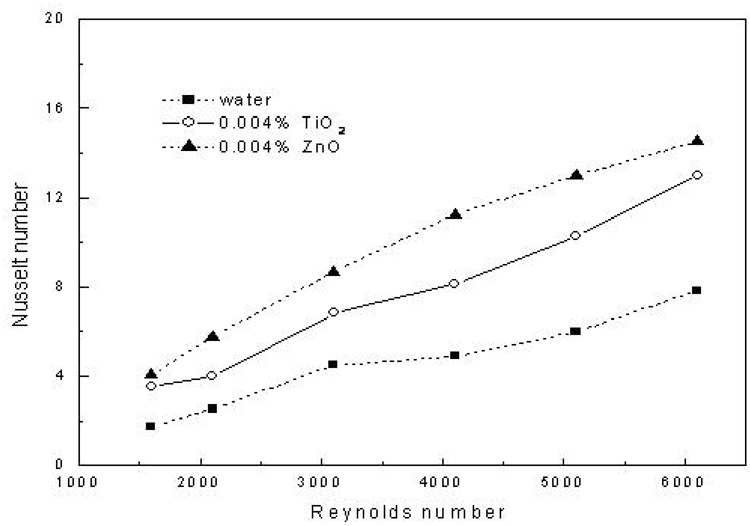

Fig. 6 Nusselt number as a function of Reynolds numbers at 0.002% concentration for different nanofluids.

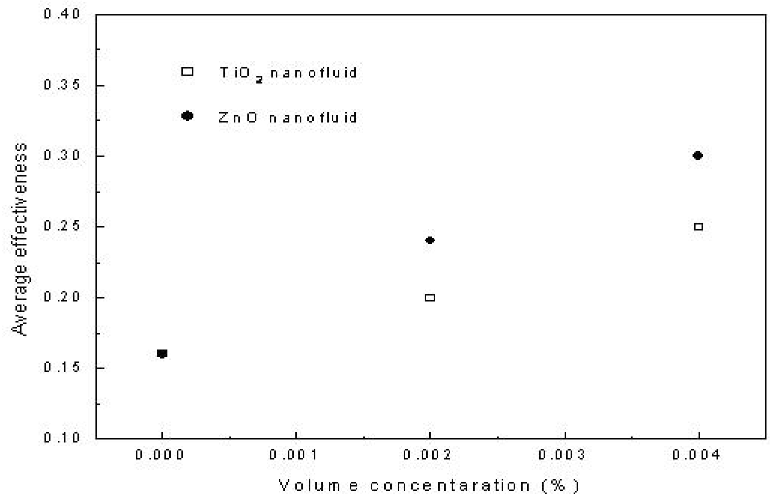

Fig. 7 Effectiveness of Heat exchanger as a function of Volume concentration for different nanofluids

Experimental Convective heat transfer coefficient and Nusslet numeber of different volume concentrations and Reynolds numbers of TiO_2 and ZnO nanofluid is shown in Fig. 3, 4,5,6 along with the data of water. It is observed that the convective heat transfer coefficient increases with increase of volume concentration and Reynold number, due to improvement in the thermophysical properties of nanofluid and increse of mass flow rates when Reynolds number increase. Effectiveness of heat exchanger with nanofluids is shown in Fig. 7 along with the data for water at various volume concentrations. Effectiveness of heat exchangers nanofluid increases with increase of particle volume concentration in a nanofluid.

Conclusions:

The convective heat transfer coefficient and flow characteristics of TiO_2 and ZnO water nanofluid flowing in a horizontal double pipe counter flow heat exchanger is experimentally investigated. Experiments were carried out at various Reynolds numbers ranging from 1600 to 6100. The effect of volume concentration and temperature of the nanofluid on the heat transfer coefficient and effectiveness were investigated. The following conclusions are drawn from the present experimental investigation.

(1) Nanofluids should be carefully prepared by considering the pH value of basefluid.
(2) TiO_2 and ZnO water nanofluid significantly gives higher heat transfer coefficients than those of the pure base fluid.
(3) The convective heat transfer coefficient increases with an increasing volume concentration of nanofluid and Reynolds number.
(4) Nusselt number also increases with increasing volume concentration of nanofluid and Reynolds number.
(5) Effectiveness of the heat exchangers increases considerably when nanofluids are used as heat transfer media.

Nomenclature:

A = Area, m^2
C = Specific heat, J/ kg K
D = Inside diameter of tube, m
h = convective heat transfer coefficient, W/m^2K
k= Thermal conductivity, W/m K
Nu = Nusselt number
ρ = Density, kg/m^3
Q = rate of heat flow, Watts.
T = Temperature, ^oC
W = Weight. kg

Subscripts:

h= hot fluid
c= cold fluid
avg= average
i=inlet
o=outlet
p= nanoparticles
w=water
z= Zinc Oxide
t=Titanium Dioxide

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