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Experimental Studies of Nanofluid TiO2/CuO in a Heat Exchanger (Double Pipe)

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Abstract

Objectives: Nanofluid TiO2/CuO was used in a heat exchanger (double pipe) for the observation of behaviour of heat transfer with flow rate and concentration of nanoparticles at ambient temperature. **Methods/Statistical Analysis:** Experimental data have been generated in double pipe heat exchanger using nanofluid and Gnielinski, Duangthongsuk and Wongwises, and Petukov correlation were used for the verification of the experimental data. **Findings:** The results predict that CuO act as a better nanoparticle in comparison to TiO2 due to high thermo-physical properties of the mixture, yield in the increase in heat transfer. Experimental results show that application of TiO2/CuO based nanofluid enhances coefficient of heat transfer by 5 % at 0.3% concentration by volume and a flow rate of 4 LPM respectively. Experimental observations were found to be fitted and revealed better agreement with Duangthongsuk and Wongwises correlations. **Application/ Improvements:** The results shows that TiO2/CuO based nanofluid are useful for improvement of the thermophysical properties yield in high heat transfer of heat exchanger used in process industries.

Keywords: Coefficient of Heat Transfer, Double Pipe Heat Exchanger, Duangthongsuk and Wongwises Correlations, Nanofluid, Nusselt Number

1. Introduction

Various industries uses water, mineral oil and ethylene glycol as a medium of transfer of heat. Some of them are power generation, microelectronics, heating processes, cooling processes and chemical industries. These heating medium have low thermal conductivity in comparison to solids (more than hundred times higher thermal conductivity) yield in less effectiveness of heat exchangers. Therefore, for improvement in thermal conductivity of fluid, various alternatives have been in use such as suspension of ultrafine solid particles (metallic, non-metallic and polymeric). But due to the small sizes (millimeter or even micrometer scale) of suspended particles, blockage of flow channels, erosion of pipelines and enhancement of pressure drop can occur. Also rheological and instability problems arises due to the small particles size. Due to these reasons, practically suspended particles slurries have not utilized in industries[1]. Various researchers have published articles related to nanofluids which increase the heat transfer coefficient of nanofluids in comparison to other fluids because of improved thermal conductivity and flow behavior of fluids. [2]Reported coefficient of heat transfer for Cu/water nanofluid in turbulent flow. The thermal conductivity and movement behavior of nanoparticles increases heat transfer. A correlation considering the nanoparticle size and volume fraction was proposed by many scientists. [3]Concluded that increase in Reynolds number increases coefficient of heat transfer for Al_2O_3/water nanofluid in laminar flow under constant wall heat flux. This was due to Brownian motion of nanoparticles in which thermal boundary layer thickness decreased due to non-uniform distribution of thermal conductivity and viscosity. [4]Found 40% increase in convective heat transfer coefficient by adding particle concentration of 6.8 vol% of Al_2O_3/water nanofluids. [5,6]Used a 4% CuO nanofluid to a commercial herringbone-type PHE and found that the fluid viscosity plays an important role in the performance of a heat exchanger. [7]Performed experiments using Al_2O_3/water nanofluid with particle size in the range of 0.01-0.3% in a circular tube of 1.812 mm inner diameter and observed an enhancement in coefficient of heat transfer. [8]Performed

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thermodynamic analysis in heat exchanger (double pipe with porous layer) and observed loss of rate of entropy generation due to high effective thermal conductivity. [9]Reported that the porous fins or baffles may increase heat transfer at definite pressure drop for porous medium of nanoparticles. The results revealed that highest heat transfer rates for the case when the flow of the hot fluid was pulsating. [10]Uses Darcy-Brinhkman-Forchheimer model and found the analytical solution in forced convection in micro-annulus filled with a porous medium. [11]Used approaches fins model and porous medium to find an analytical and numerical solution on the use of water-CuO nanofluid as a coolant in a micro channel heat sink. [12]Performed experiments using CuO-Water as nanofluid in light water nuclear reactor and showed that at low concentration of nanofluid and higher Reynolds number, the heat transfer coefficients increases. [13]Utilizes silver nanofluid in heat transfer applications in automobile industry at different concentration, size of nanoparticle and variation in pH and found to be effective nanofluid. [14]Used copper nanofluid to find the effects of MHD in nanofluid. The results predict that nanofluid possess good rate of heat and mass transfer. A few studies were reported on the application of TiO_2/CuO nanofluid in a heat exchanger (double pipe). Therefore, this paper reported experimental studies of utilization of nanofluid TiO_2/CuO in a heat exchanger (double pipe).

2. Experimental

2.1 Materials

The Merck Chemical Company was supplied the chemicals used for this study. The size of nanofluid CuO and TiO_2 was 30-50 nm and 10-20 nm in diameter respectively. The surfactant Triton X-100 was used as a mixing agent.

2.2 Experimental Set-up

The apparatus used for this study was shown in Figure 1. Experimental observations have been performed for heat transfer due to convection with differ flow behavior i.e. laminar and turbulent using nanofluid TiO_2/CuO with a concentration range of 0.1-0.3 volume%. Experimental set up consists of a test section (straight steel with inner tube dimension d_o = 18mm, d_i = 15mm and outer tube dimension D_o = 36mm, D_i = 132mm. length of tubes are 1.5m), pump, reservoir tank, and valves for setting co-current flow and counter-current flow. The surface of tube was insulated thermally (150 mm thick blanket) for minimization of heat loss from the tube to the ambient. The variation of flow of fluid was 1 to 4 LPM. Heated fluid was re-circulated to keep constant temperature at the inlet of the test section.

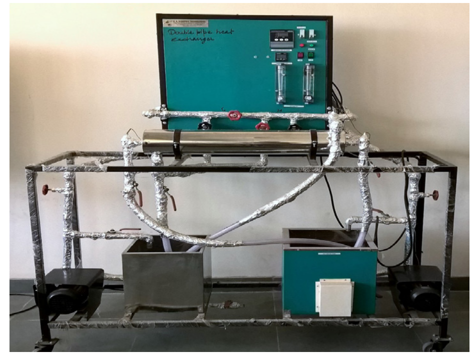

Figure 1. Experimental Setup of double pipe heat exchanger.

2.3 Nanofluid Physical Properties

In this study, the thermo-physical properties considered for TiO_2 are:

Density= 3900 kg/m^3, Specific heat = 697 J/kg K, Thermal conductivity = 11.8 W/m K

Base fluid properties are:

Density= 994.7 kg/m^3, Specific heat = 4170.7 J/kg K, Thermal conductivity = 0.615 W/m K,

Viscosity= 0.000547 kg/ms

Properties of CuO are:

Density= 6310 kg/m^3, Specific heat = 550.5 J/kg K, Thermal conductivity = 37 W/m K

Nusselt number and Reynolds number was determined using the experimental observations. The thermo physical properties were calculated on mean bulk temperature of Nanofluid. Effective viscosity, density, heat capacity and thermal conductivity were calculated using equation 1, 2, 3 and 4 and tabulated in Table 1 and 2.

Table 1. Effective Thermo physical properties of TiO2 – Water Sample

Sample	Density (Kg/m^3)	K (W/mK)	C_p (J/KgK)	Viscosity (Kg/ms)
Water	994.7	0.615	4170.7	0.000547
Water + 0.1 % TiO_2	997.94	0.617	4177.405	0.000548
Water + 0.2% TiO_2	1001.171	0.619	4183.962	0.000549
Water + 0.3% TiO_2	1004.71	0.620	4204.071	0.00055

Table 2. Effective Thermo physical properties of CuO – Water Sample

Sample	Density (Kg/m^3)	K (W/mK)	C_p (J/KgK)	Viscosity (Kg/ms)
Water	994.7	0.615	4170.7	0.000547
Water + 0.1 % CuO	1000.0153	0.618	4148.11	0.000548
Water + 0.2% CuO	1005.3306	0.620	4125.76	0.000549
Water + 0.3% CuO	1010.6453	0.62222	4103.643	0.00055

1. Viscosity of Nano fluid: - Drew and Passman relation

$$\mu_{nf} = \mu_{bf}(1 + 2.5\emptyset) \quad (1)$$

2. Density – Choi Correlation

$$\rho_{nf} = (1 - \emptyset)\rho_{bf} + \emptyset\rho_p \quad (2)$$

3. Heat Capacity equation :Xuan and Roetzel

$$C_{pnf} = \frac{(1 - \emptyset)\rho_{bf} C_{p_{bf}} + \emptyset\rho_p C_{p_p}}{\rho_{nf}} \quad (3)$$

4. Effective thermal conductivity: Yu and Choi Model:

$${}_f = \frac{[K_p + 2K_{bf} + 2(K_p - K_{bf})(1+\beta)^3\emptyset]K_{bf}}{[K_p + 2K_{bf} - (K_p - K_{bf})(1+\beta)^3]} \quad (4)$$

2.4 Theoretical Correlations

Nusselt number was calculated using the observations obtained from the experimental data at different conditions. Assumption of steady state was considered for the study and the behavior of heat transfer at different flow rate (laminar and turbulent flows), coefficient of heat transfer and Nusselt Number was determined by following equations respectively.

$$Q = mC_p\Delta T = mC_p(T_{in} - T_{out}) \quad (5)$$

$$h = \frac{Q}{A \times \Delta T_{LMTD}}. \quad (6)$$

$$Nu = \frac{hd}{k_{eff}} \quad (7)$$

Validation of the experimental data was performed using correlation available in the literature and shown in Table 3.

Table 3. Theoretical Correlations

Author	Model Equation
Gnielinski [15]	$Nu_D = \frac{\left(\frac{f}{8}\right)(Re_D - 1000)Pr}{1 + 12.7\left(\frac{f}{8}\right)^{\frac{1}{2}}(Pr^{\frac{2}{3}} - 1)}$, $f = (0.79\ln(Re_D) - 1.64)^{-2}$.
Duangthongsuk and Wongwises [16]	$Nu = 0.074Re^{0.707}Pr^{0.385}\varphi^{0.074}$
Petukov [17]	$Nu_D = \frac{\left(\frac{f}{8}\right)RePr}{1.07 + 12.7\left(\frac{f}{8}\right)^{\frac{1}{2}}(Pr^{\frac{2}{3}} - 1)}$, $f = (0.79\ln(Re_D) - 1.64)^{-2}$

3. Results and Discussion

All the experimental analysis was performed by CuO/ TiO_2 water nanofluids by varying the concentration of nanoparticles from 0.1% to 0.3% by volume and different flow rate (1-4 LPM). The temperature was maintained at 30±3°C for all runs. The observations from this study were summarized as below.

3.1 Effect of Concentration of Nanoparticles

Figure 2 and 3 shows the effect of nanoparticle concentration on Nusselt number with Reynolds Number. From these figures, it can be concluded changes in concentration of nanoparticles increases the Reynolds number hence Nusselt Number. It was due to increase in heat transfer and Reynolds number on addition of nanoparticles in the fluid which improved thermo physical properties of the mixture. Similar results were reported by[18,19]. The variation of CuO nanoparticle was represented in Figure 4. This revealed that heat transfer enhancement was more in comparison to TiO_2 for same volume concentration. This may be due to more thermal conductivity of CuO than TiO_2.

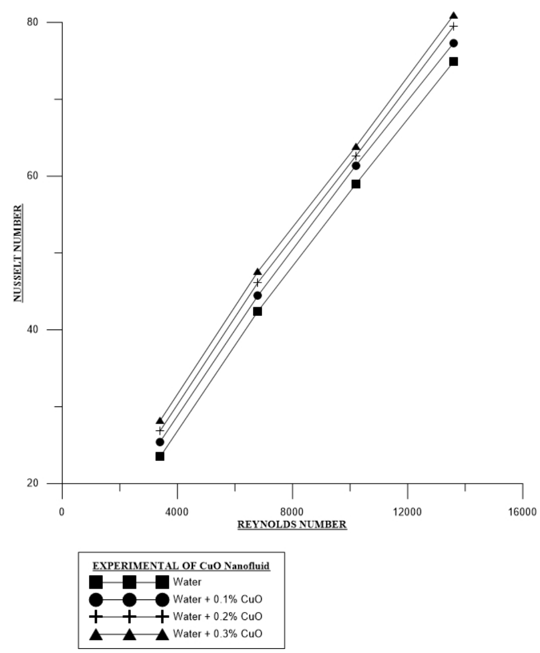

Figure 2. Variation of Nusselt number with Reynolds number for CuO nanofluid.

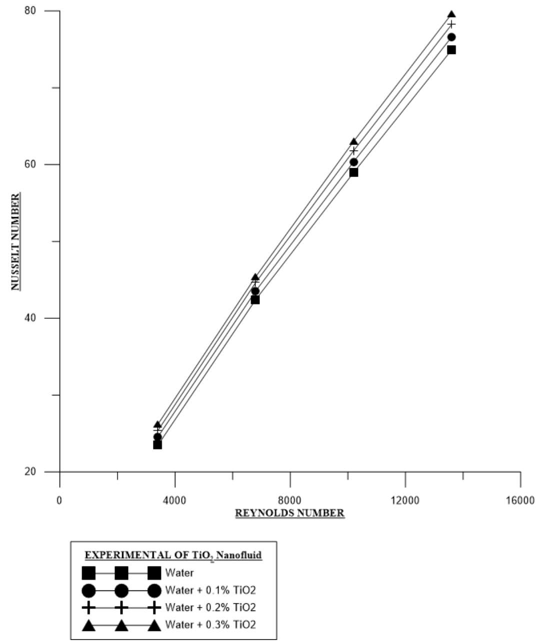

Figure 3. Variation of Nusselt number with Reynolds number for TiO2 nanofluid.

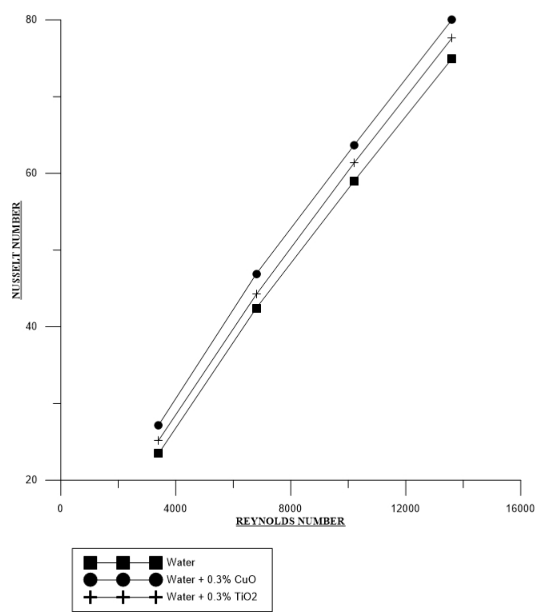

Figure 4. Variation of Nusselt number with Reynolds number for 0.3% CuO and 0.3% TiO2 nanofluid.

3.2 Validation of Experimental Data and Correlation

Figure 5 and Figure 6 shows validation of experimental data at 0.3 volume% of TiO_2 and CuO Nanofluid with correlations given by Gnielinski, Duangthongsuk and Wongwises, and Petukov. It was observed that Gnielinski model correlation was best fitted with experimental results in comparison to other model.

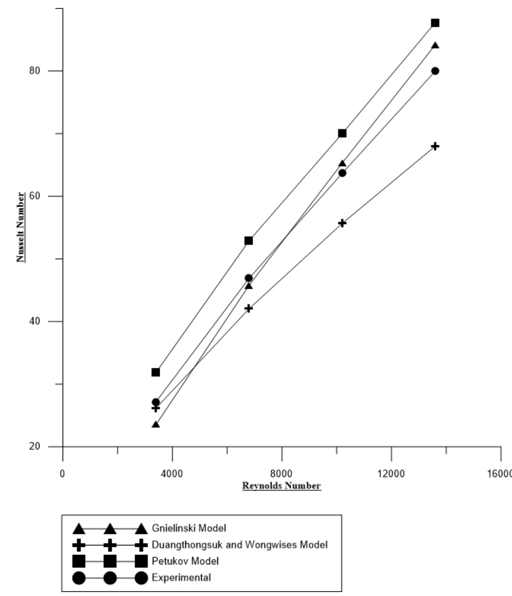

Figure 5. Validation of results with theoretical correlation and Experimental (.3% CuO concentration).

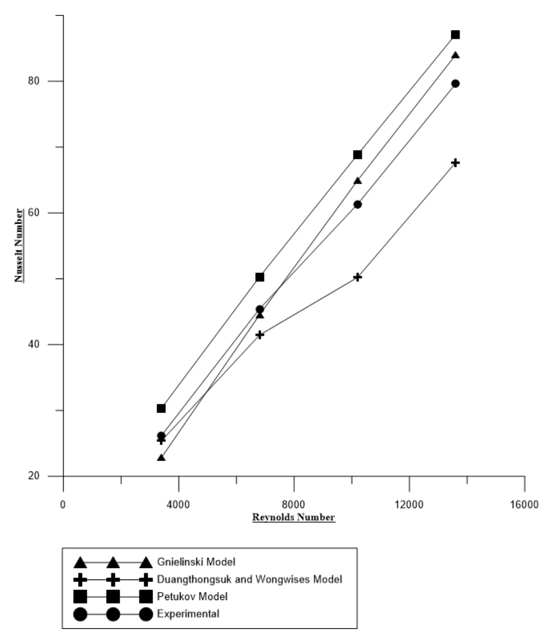

Figure 6. Validation of results with theoretical correlation and Experimental (.3% TiO2 concentration).

4. Conclusions

Performance of heat exchanger (double pipe) has been studied using experimental observation and numerical techniques. Results have been shown by highlighting the variation of flow rate and concentration of nanoparticles. Experimental results show that application of TiO_2/CuO based nanofluid enhances coefficient of heat transfer with concentration and flow rate (increase by 5 %) respectively. Gnielinski model correlation found to be best fitted with the experimental observations. A theoretical and experimental result shows that distribution of nanoparticles in homogeneous and stabilized manner increases the coefficient of heat transfer significantly.

5. Acknowledgement

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Nomenclature

d_o: Outer diameter of inner tube of heat exchanger
d_i: Inner diameter of inner tube of heat exchanger.
D_o: Outer diameter of outer tube of heat exchanger.
D_i: Inner diameter of outer tube of heat exchanger.
μ_{nf} : Viscosity of nanofluid ,(kg/m^3)
ρ_{nf} : Density of nanofluid ,(kg/m^3)
C_{pnf} : Heat Capacity of nanofluid , (J/kgK)
K_{nf} :
Effective Thermal Conductivity of nanofluid ,

(W/mK)

μ_{bf} : Viscosity of Base Fluid, (kg/ms)

ρ_{bf} : Density of Base Fluid (kg/m^3)

K_{bf} :

Effective Thermal Conductivity of Base Fluid (W/mK)

ρ_p : Density of Particle, (kg/m^3)

K_p :

Effective thermal conductivity of particle (W/mK)

$C_{p\_}$: Heat Capacity of Particle(W/mK)

div: divergencedivergence

K: Thermal Conductivity (W/mK)

C_p: Specific Heat (J/kgK)

T: Temperature (K)

m: Mass Flow Rate (kg/sec)

T_{in}: Inlet Temperature of Hot and Cold Fluid (K)

$T_{out:}$ Outlet Temperature of Hot and Cold Fluid (K)

Q: Rate of Heat Transfer(W)

ΔT_{LMTD}: Log Mean Temperature Difference

A: Cross Sectional Area of Shell(mm^2)

Nu: Nusselt Number

H: Heat Transfer Coefficient(W/m^{2}k)

D: Diameter of Tube (mm)

K_{eff}: Effective Thermal Conductivity(W/mK)

Nu_D: Nusselt Number (Gnielinski Model)

f: Darcy Friction Factor

Re_D: Reynolds Number of the Flow

Pr: Prandlt Number

LPM: Litre per Minute

Mathematical Symbols

ln: Natural LogarithmNatural Logarithm

≤: Less Than Or Equal To

Less Than Or Equal To

%: Percentage

Greek letters

ρ : Density (kg/m^3)

Ø : Volume Fraction

β: Ratio of the surface area of a sphere with a volume equal to that of the particle to the surface area of the particle (β = 0.1)

Subscripts

nf Refers to nanofluids

bf Refers to base fluids

LMTD Log Mean Temperature Difference

p Refers to particle

eff Refers to effective value

in Refers to inlet condition

out Refers to outlet condition