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ORIGINAL RESEARCH PAPER

Investigation of Heat Transfer Coefficient Enhancement for CuO/TiO_2 Nanocomposite in a Tube Heat Exchanger

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ABSTRACT: In order to improve the efficiency and rate of heat transfer in heat exchangers, various techniques such as increasing the heat transfer coefficient are proposed. This study is devoted to the investigation of heat transfer coefficient variations due to the addition of CuO, TiO_2 and CuO/TiO_2 nanoparticles into a shell and tube heat exchanger. CuO/TiO_2 nanocomposite was synthesized using mechanical technique. Particle size analyzer was used to determine the size distribution of CuO/TiO_2 nanocomposite. The results indicated an increase in the nanofluid heat transfer coefficient and overall heat transfer coefficient by increasing the nanoparticle composition and temperature. The heat transfer coefficients of CuO nanofluid are higher than that of TiO_2 and the heat transfer coefficient of the nanocomposite is the highest. The heat transfer coefficient and overall heat transfer coefficient were enhanced 4.58 to 12.42 times and 4.01 to 12.33, respectively by increasing nanocomposite mass fraction. The highest heat transfer coefficients occur at the 75/25% CuO/TiO_2 nanocomposite mass ratio.

KEYWORDS: *Nanocomposite; Nanofluid; Heat transfer coefficient; Shell and tube heat exchanger*

INTRODUCTION

In order to improve the efficiency and rate of heat transfer in heat exchangers, various techniques such as increasing the heat exchange area and changing the heat transfer medium are proposed. The purpose of changing the heat transfer medium is the replacement of common fluids (e.g. water and ethylene glycol) with higher heat transfer coefficient mediums. This has led to many research projects during the last decade. One of these alternatives are nanofluids. The addition of nano-scale particles into conventional fluids can lead to significant improvement in thermal properties [1, 2].

Anoop et al. [3] studied the effect of silica/water nanofluid on the overall heat transfer coefficient and pressure drop in plate and shell and tube heat exchangers. The heat transfer coefficient of the nanofluid was dependent on the flow rate and nanofluid concentration in both cases. Also, pressure drop was higher than the base fluid which may limit its application in some cases. Farajollahi et al. [4], measured thermal transfer properties of water/alumina and water/titania nanoparticles in a shell and tube heat exchanger under turbulent flow conditions.

The effect of peclet number and nanofluid concentration on heat transfer characteristics was studied. Heat transfer efficiency is increased by adding nanoparticles to the base fluid. Also, the heat transfer characteristics of Titania nanofluid with an optimum concentration (0.3 vol. %) and a certain peclet number (20,000-60,000) was higher than that of alumina nanofluid.

Albadr et al. [5], investigated the effect of Al_2O_3 nanofluid concentration on the convective heat transfer and friction factor through a shell and tube heat exchanger under counter-current and turbulent flow conditions. Heat transfer coefficient is enhanced by increasing nanofluid concentration and flow rate, which also result in friction factor enhancement. Also, Lotfi et al. [6], reported the effect of MWCNT/water nanofluid heat transfer in a shell and tube heat exchanger.

The results showed an increase in the heat transfer coefficient compared to water as the base fluid. Sajadi et al. [7] investigated the heat transfer and pressure drop characteristics of ZnO/water nanofluid in a circular tube under constant wall temperature conditions. Based on the results, increasing the nano-particle concentration leads to the enhancement of heat transfer coefficient, overall thermal performance and pressure drop. Zeinali Heris et al. [8] studied the convective heat transfer of CuO/water and Al_2O_3/water nanofluids through a circular tube under laminar flow conditions with constant wall temperature.
The results indicated that increasing the nanofluid concentration and peclet number results in the enhancement of heat transfer coefficient compared to the water/water system.

Also, the enhanced heat transfer of Al_2O_3/water nanofluid was higher than that of the CuO/water nanofluid. Ghozatloo et al. [9] reported the enhancement of water/grahene (nano-sheet) nanofluid heat transfer in a shell and tube heat exchanger under laminar flow conditions.

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Nomenclature

C	Cost per exergy unit ($/J)	tot	Total
$\dot{C}$	Exergy cost rate ($/hr)		**Greek Symbols**
$\dot{E}$	Total exergy rate (kW)	Δ	Gradient
$\dot{Z}_K$	Capital investment cost rate ($/hr)		**Abbreviations**
		AC	Air cooler
	Superscripts	C	Compressor
AV	Avoidable	C3MR	Propane precooling
EN	Endogenous	D	Flash drum
EX	Exogenous	DMR	Dual mixed refrigerant
UN	Unavoidable	HX	Heat exchanger
CH	Chemical	hr	Hour
		LNG	Liquefied natural gas
	Subscripts	MR	Mixed refrigerant
D	Destruction	MFC	Mixed fluid cascade
i	Substance i, inlet	NG	Natural gas
k	kth component	NGL	Natural gas liquids
L	Loss	T	Tower
O	Outlet	V	Expansion valve
		T	Temperature (°C)

The results indicated that the convective heat transfer coefficient was enhanced by increasing nanofluid concentration and fluid temperature. An increase in the graphene concentration from 0.025 to 0.1 wt.% increased the heat transfer coefficient of graphene nanofluid by 15.3% at 25°C, whereas at 38°C, 23.9% enhancement in the heat transfer coefficient was occurred. Godson et al. [10] studied the heat transfer of silver/water nanofluid in a shell and tube exchanger. The influence of inlet temperature, Reynolds number, nanofluid concentration and mass flow rate on LMTD, effectiveness, convection heat transfer and pressure drop is studied in this work. The results showed that heat transfer coefficient, pressure drop, LMTD and effectiveness were enhanced by increasing nanofluid concentration and Reynolds number. Gurav et al. [11] studied the heat transfer of water/Au nanofluid. The experimental results showed that under identical conditions, the nanofluid reduced in thermal resistance of heat tubing significantly compared to the base fluid. Madhesh et al. [12] studied the convective heat transfer, pressure drop, friction factor and rheological characteristics of Cu-TiO_2 hybrid nanofluid in a heat exchanger. The results revealed an increase in the Nusselt number by 52%, the convective heat transfer coefficient by 49% and the overall heat transfer coefficient by 68%.

Nanocomposites of nanoparticles are also previously applied in various fields such as drilling mud [13], photocatalytic degradation [14] and water treatment [15] and proved their performance due to synergetic effects. As a result, nanocomposite configuration can be proposed as a promising alternative for heat transfer coefficient enhancement upon addition to water as the base fluid. In this study, CuO/TiO_2 nanocomposite was provided by mechanical technique. Then, the prepared nanofluid was applied in a shell and tube heat exchanger. Finally, the effect of nanofluid concentration on the heat transfer and overall heat transfer was studied at various temperatures.

EXPERIMENTAL RESULTS

Materials and Methods

CuO nanoparticle was provided by Sigma-Aldrich Co. with a particle size < 50 nm and specific surface area > 80 m^2/gr. TiO_2 nanoparticles were purchased from Tecnano Co. with an average particle size of 10-15 nm and specific surface area of 100–150 m^2/gr. Ethanol and methanol were produced by Merck Co.

Preparation of CuO/TiO_2 Nanocomposite

TiO_2 and CuO nanoparticles with certain ratios were added to ethanol and stirred by magnetic stirrer for ~ 30-45 min, then sonicated for 30 min. The aqueous dispersion was filtered and dried at room temperature for 24 h. Finally, the as-produced nanopowder was annealed at 550 ºC (4.7 C/min) for 2 h. with 75-25%, 50-50% and 25-75% mass ratios of CuO and TiO_2.

Nanofluid Preparation

Surfactant addition, pH control and ultrasonication or a combination of these can be applied to prevent precipitation and nanofluid stabilization. In this study, ultrasonication is applied, without using any dispersants or stabilizers which can alter nanofluid properties. In order to prepare nanofluids of CuO, TiO_2 and the nanocomposites, nano-powders with certain weight fractions were added to deionized water (2 lit), separately and then stirred under high speed magnetic stirring for 45-60 min. At last, the mixture was sonicated by ultra-sonication (Power =100 W) for 30-40 min in order to disperse the nanoparticles in the based fluid. The weight percent of the nanoparticles and nanocomposites used were 0.1%, 0.01% and 0.001%.

Heat exchange experiments

To study the effect of nanofluid heat transfer coefficient on heat exchange characteristics, an experimental setup was designed (Fig. 1). The heat exchanger used in this study is shell and tube type with counter-current flow. The nanofluid flowing through the shell is the coolant and deionized water is the heating fluid. The heating loop includes a pump, hot fluid tank, heater, temperature controller and also measurement of tube inlet and outlet temperatures. The temperature controller and the measurement of tube and shell temperature inlet and outlet systems use SAMWON ENG thermometer with an accuracy of ±0.1 ^{0}C. Also, a k-type thermocouple was used to measure the flow temperature. The cooling loop consists of a pump, nanofluid tank, temperature controller and also measurement of shell inlet and outlet temperatures. The shell and tube were made of pyrex and copper, respectively.

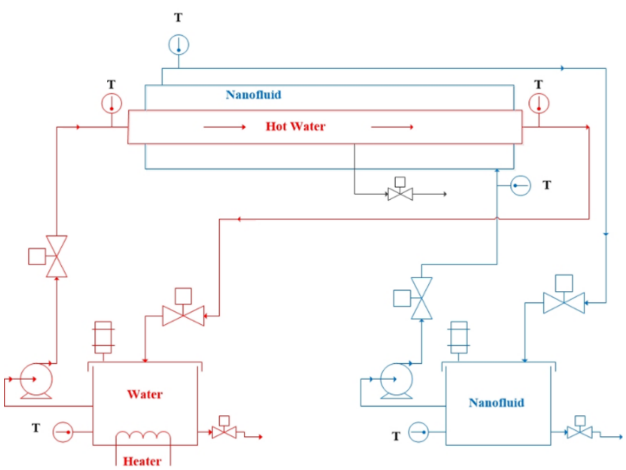

Fig.1. Schematic of experiential setup

In order to measure the heat transfer coefficient and the overall heat transfer coefficient, experiments were carried out with water/water, titania/water nanofluid, CuO/water nanofluid, nanocomposite/water nanofluid at various concentrations in the shell-tube heat exchanger. The experiments were performed at 50 ºC and 60 ºC.

Heat Transfer Calculations

The rate of heat transfer for the hot fluid is calculated from:

$$Q_w = \dot{m}_w C_{pw}(T_4 - T_3)_w \tag{1}$$

Where Q_w, $\dot{m}_w$, C_{pw} and $(T_4 - T_3)_w$ are the heat transfer rate of hot fluid, mass flow rate, specific heat capacity and temperature difference between the exit and inlet hot fluids, respectively. The heat transfer rate of cold nanofluid is calculated by:

$$Q_{nf} = \dot{m}_{nf} C_{pnf}(T_1 - T_2)_{nf} \tag{2}$$

Where Q_{nf} $\dot{m}_{nf}$, C_{pnf} and $(T_1 - T_2)_{nf}$ are the heat transfer rate of cold fluid, mass flow rate, specific heat capacity and temperature difference between the inlet and outlet cold fluids, respectively. The average heat transfer between the hot and cold fluid is calculated as follows:

$$Q_{avg} = \frac{(Q_w + Q_{nf})}{2} \tag{3}$$

The overall heat transfer coefficient from the copper tube outer surface is calculated from the following equation:

$$U_o(exp) = Q_{avg}/(A_o \Delta T_{LMTD}) \tag{4}$$

Where, A_o is the cross-section of the external copper tubes and ΔT_{LMTD} is the logarithmic mean temperature difference in the counter current flow heat exchanger.

RESULTS AND DISCUSSION

Particle Size Analysis

The CuO/TiO_2 nanocomposite is characterized by particle size analyzer (Horiba LB-550, range of 0.001-6 µm). Figure 2 shows the particle size distribution of the nanocomposite. The average particle size of the produced nanocomposite is ~ 62 nm.

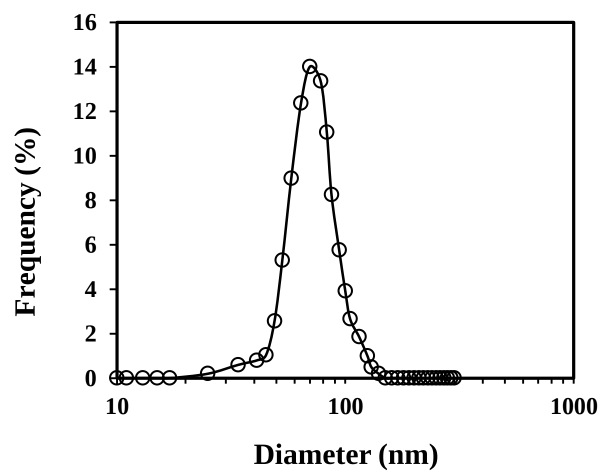

Fig. 2. Particle size distribution of CuO/TiO_2 nanocomposite

Effect of Nanofluid Concentration

The heat transfer coefficient in the water/water system is 0.5865 W/m^2 ºC which is expected to be enhanced by the addition of nanoparticles to the base fluid. The effect of CuO and TiO_2 nanofluids on the heat transfer coefficient at 50 ºC is shown in Figure 3. The results indicate that increasing the nanofluid concentration results in the enhancement of heat transfer coefficient, which implies the high heat exchange rate between the shell and tube due to the enhanced thermal conductivity and reduced specific heat capacity and thermal boundary layer thickness. CuO nanofluid is more effective than TiO_2. TiO_2 and CuO, enhance the heat transfer coefficient 6.16 and 9.81 times compared with the base fluid, respectively.

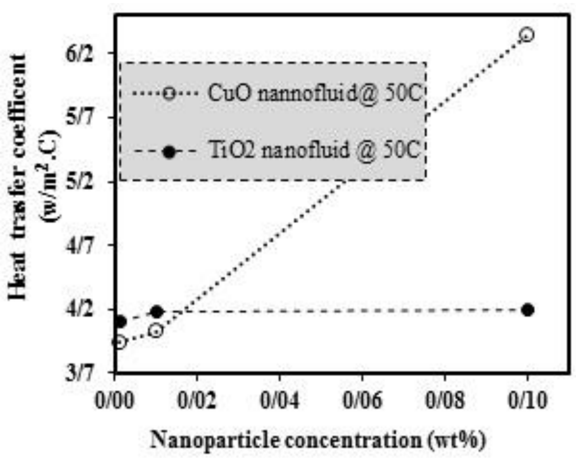

Fig. 3. Effect of CuO and TiO_2 nanofluid on heat transfer coefficient

Effect of concentration on the overall heat transfer coefficient is indicated in Figure 4.

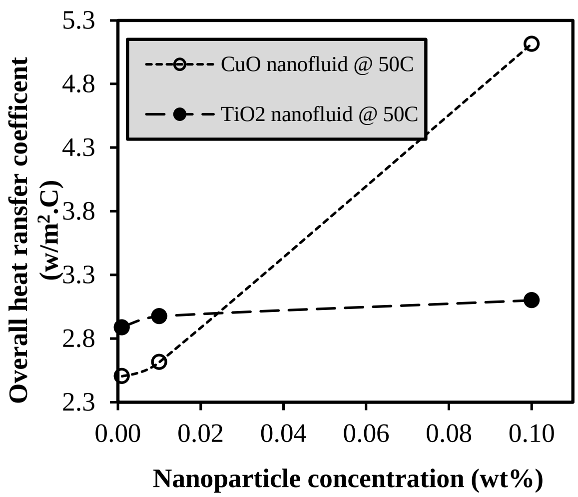

Fig. 4. Effect of CuO and TiO_2 nanofluid on overall heat transfer coefficient

Presence of nanoparticles result in a significant increase in the nanofluid overall heat transfer coefficient in nanofluid/water system compared with the water/water system (0.5895 $W/m^{2o}C$).

The overall heat transfer coefficient is enhanced by increasing the nanofluid concentration which indicates an increase in the heat transfer in the water/nanofluid system. TiO_2 and CuO increase the overall heat transfer coefficient up to 4.26 and 7.68 times compared with the base fluid.

Effect of temperature

Effect of temperature on the heat transfer coefficient and the overall heat transfer coefficient of CuO and TiO_2 nanofluids at 50 ºC and 60 ºC are shown in Figures 5 and 6. The results reveal that the heat transfer coefficient and the overall heat transfer coefficient of CuO nanofluid show a uniform and stable trend at higher temperatures and the nanofluid is independent of concentration in contrast to the TiO_2 nanofluid.

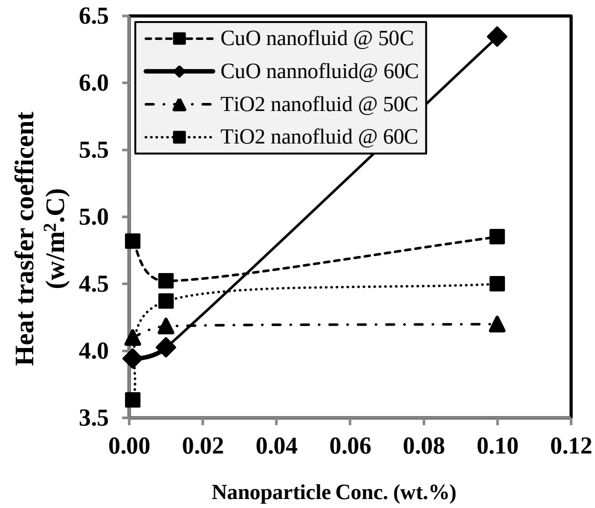

Fig. 5. Effect of temperature on heat transfer coefficient

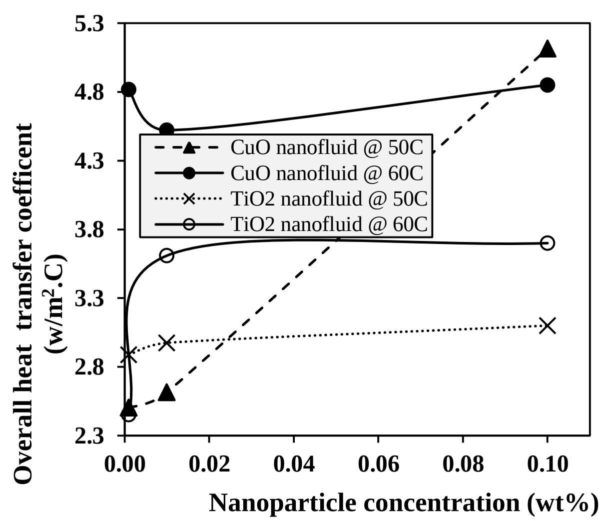

Fig. 6. Effect of temperature on overall heat transfer coefficient

Effect of nanocomposite concentration

Effect of nanofluid concentration with 75-25, 50-50 and 25-75 of CuO/TiO_2 mass ratios, on the overall and heat transfer coefficients are given in Figures 7 and 8, respectively.

The results show that by increasing the nanocomposite concentration, the heat transfer coefficient and the overall heat transfer coefficient are increased.

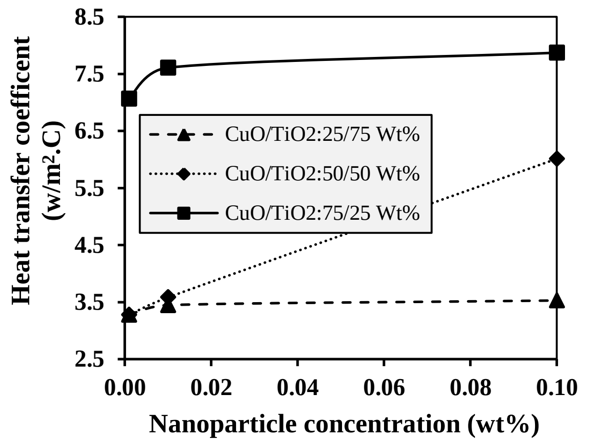

Fig. 7. Effect of nanofluid produce from nanocomposite on heat transfer coefficient

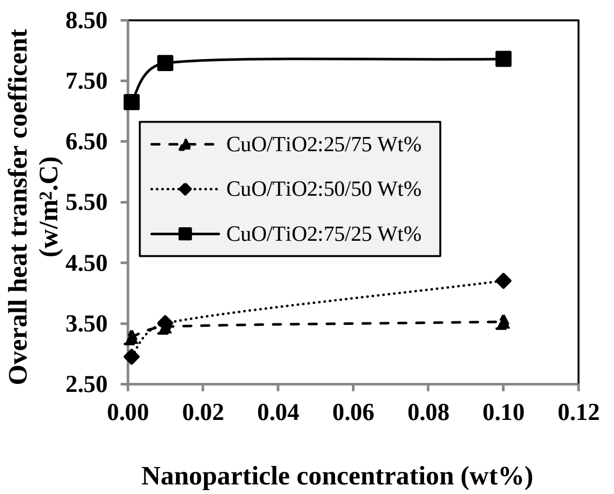

Fig. 8. Effect of nanofluid produced from nanocomposite on the overall HTC.

The improvement of heat transfer coefficients and the overall heat transfer coefficient of the nanofluid containing the produced nanocomposites are higher than those of the CuO and TiO_2 nanoparticles due to the synergetic effect of nanoparticles in the nanocomposite. The increase in heat transfer coefficient and overall heat transfer coefficient in the water-nanocomposite nanofluid system compared to water/water system is given in Table 1.

CONCLUSIONS

In this work, CuO/TiO_2 nanocomposite was synthesized via mechanical technique and characterized by particle size analysis. CuO/TiO_2 nanocomposite, CuO and TiO_2 nanofluids were prepared. The effect of nanofluid concentration and temperature on heat transfer coefficient and overall heat transfer in a shell and tube heat exchanger are investigated. The results show that: - - Heat transfer coefficient and overall heat transfer of nanofluids are higher than that of the base fluid and are enhanced by increasing the nanofluid concentration,

- Heat transfer coefficient of TiO_2 nanofluid is higher than that of CuO but the heat transfer coefficient variation of CuO nanofluid is higher than that of TiO_2,
- The nanofluid heat transfer coefficient variations with concentration at 60 ºC are higher than that of 50 ºC.
- The heat transfer coefficients of the nanocomposite nanofluid is higher than that of CuO and TiO_2 nanofluids separately and the base fluid.
- The highest heat transfer coefficient occur at 75/25 CuO/TiO_2 nanocomposite weight ratio.

Table 1
Heat transfer coefficient enhancement

	Heat transfer coefficient			**Overall heat transfer coefficient**		
CuO/TiO_2 Ratio / **Nanofluid wt. %**	**25-75%**	**50-50%**	**75-25%**	**25-75%**	**50-50%**	**75-25%**
0.001	4.59±0.1	4.58±0.1	11.04±0.1	4.01±0.1	4.55±0.1	11.12±0.1
0.01	5.11±0.1	4.88±0.1	11.98±0.1	4.94±0.1	4.85±0.1	12.22±0.1
0.1	9.25±0.1	5.01±0.1	12.42±0.1	6.13±0.1	4.99±0.1	12.33±0.1

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