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STUDY OF HEAT TRANSFER ENHANCEMENT BY CUO-WATER NANOFLUID IN DOUBLE PIPE HEAT EXCHANGER

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ABSTRACT

Heat transfer through a fluid medium is important in several engineering applications and is largely convection dominated. However, the convective heat transfer coefficient is strongly dependent on the thermal conductivity of fluid. A nanofluid is a stable colloidal suspension of a low volume fraction of ultrafine solid particles of nanometric-dimension dispersed in conventional heat transfer fluid. In this study the heat transfer parameters like convective heat transfer coefficient and Nusselt number are studied for CuO-water nanofluid samples of different volumetric concentration. These tests are to be compared with the benchmark water-water heat transfer experiment, to look for possible enhancement.

KEYWORDS

Heat transfer, Heat Exchanger and LMTD value.

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INTRODUCTION

High performance heating and cooling are most important need of many industrial technologies. But, the relatively low thermal conductivity of heat transfer fluids is the main limitation in high performance cooling. *Nanofluids* (suspension of nanoparticle in fluid) is the term coined by Choi (1995) to describe new class of nanotechnology-based heat transfer fluids that exhibit superior thermal properties than those of their host fluids. Nanofluids are stable suspensions engineered by uniformly dispersing nanoparticles with average sizes below 100nm in conventional heat transfer fluids such as water, oil, and ethylene glycol.

Eastman *et al*[1] reported breakthrough when a 40% enhancement of conductivity was achieved with only 0.3% concentration of 10nm-sized copper nanoparticles suspended in ethylene glycol with thioglycolic acid as a stabilizing agent. Patel *et al*[2] used gold and silver nanoparticles and found dramatic enhancement in thermal conductivity for vanishingly small concentrations. At room temperature, the conductivity of toluene-gold nanofluid was enhanced by 3-7% for a volume fraction of only 0.005-0.011%, whereas the enhancement for water-gold nanofluid was 3.2–5% for a vanishingly small concentration of 0.0013–0.0026%. The enhancement was relatively low for silver based nanofluids as the particle size was larger (60-80nm). U. S. Choi, Z. G. Zhang *et al.* (2001)[3] worked on carbon nanotube (CNT) based nanofluids and showed the greatest enhancement when a phenomenal 160% increase in thermal conductivity was observed with just 1% volume fraction of CNTs in synthetic poly (α-olefin) oil. Also CNT nanofluids were found to have a nonlinear relationship between thermal conductivity and concentration at low volume fractions of CNTs.

Hybrid alloy nanoparticle of Aluminium dominated Al-Cu binary alloy, $Al_{70}Cu_{30}$ suspended in ethylene glycol were tested for the first time Manoj Chopkar *et al.* (2006)[4]. It was found that for same volumetric ratio, thermal conductivity of nanofluid significantly increases with decreasing size. For 0.5 % vol., the enhancement was 40% for 10nm and just 2.5% for 80nm diameter. Sarit Kumar Das *et al*[5] investigated thermal conductivity of Al_2O_3 and CuO water based nanofluids and observed a dramatic increase in the enhancement of conductivity with temperature (2 to 4-fold increase over a temperature range of 21°C to 51°C). With 1% particles at room temperature 21°C the enhancement in only about 2%, but at 51°C this value increases to about 10.8%.

Experimental setup

The experimental setup consists of a test heat exchanger with hot fluid as water and cold fluid as the nanofluid sample. The heat exchanger is a double pipe heat exchanger with 25.4mm inner diameter, 30mm outer diameter and 600mm in length with copper as tube material. A 1kW water heater is used to heat the hot fluid. The power supply to heater passes through an ammeter and a voltmeter to measure the instantaneous power input to the hot fluid. Two pressure gauges, each before and after the heat exchanger measures the pressure drop in nanofluid flow in heat exchanger.

Design of experiment

The factors that needed to be measured for heat transfer enhancement study are

Heat transfer coefficient of nanofluid, h_{nf}

Nusselt number of nanofluid, Nu_{nf}

These factors can be measured by varying the Volumetric concentration factor, **φ** (sample vol. concentration can be varied from 0 – 1% in steps of 0.25%).

The instantaneous heat supplied to the hot fluid can be calculated as

$$Q = VI$$

Where, V and I are the instantaneous values voltage and current supplied to the heater, measured by a voltmeter and ammeter respectively. The fluid temperatures are read directly from indicator and are represented as follows,

T_1 = nanofluid inlet temp., T_2= nanofluid outlet temp., T_3= water inlet temp., T_4= water outlet temp.

From this the Log mean temp difference (LMTD) is calculated as

$$LMTD = \frac{\Delta T_1 - \Delta T_2}{ln\frac{\Delta T_1}{\Delta T_2}}$$

The overall heat transfer coefficient, **U** is given as,

$$U = \frac{Q}{A_s \times LMTD}$$

Where A_s= surface area of the tube section = $\pi D_i L$.

The Convective heat transfer coefficient of nanofluid, $\boldsymbol{h_{nf}}$ is then given by,

$$\frac{1}{U} = \frac{1}{h_{nf}A} + \frac{ln\frac{r_2}{r_1}}{2\pi k_{metal}L}$$

Here the thermal conductivity of tube material (copper) is taken as K_{metal} = 385 W/m-K.

Lastly the Nusselt number of nanofluid, $\boldsymbol{Nu_{nf}}$ is calculated by

$$Nu_{nf} = \frac{h_{nf} D}{K_{nf}}$$

The thermal conductivity for nanofluid is an empirical finding. Hence there are many empirical relations in literature by different researchers. A more common correlation gives the thermal conductivity relations as

$$K_{nf} = \frac{K_p + 2K_f + 2\varphi(K_p - K_f)}{K_p + 2K_f + \varphi(K_p - K_f)}$$

Nanofluid preparation

In this study, a two-step process is used to prepare the nanofluids by separately synthesizing the nanoparticles and then dispersing it in the base fluid. Copper oxide (CuO) nanoparticles with 10nm diameter (supplied by amnium technologies, Pune) are chosen for this study. The CuO nanoparticle quantity calculated based on the amount of base fluid required to have a fully developed flow and the required volumetric concentration is measured using an electronic microscale weighing balance.

This is mixed with measured Deionized water with stabilizer/surfactant such that the desired concentration ratio is obtained and is magnetically stirred to get a uniform mixture. Since nanoparticle powders tend to agglomerate due to strong Van der Waals forces, the mixture is transferred in an Ultrasonic bath for sonication. Sonication is the process of breaking this agglomeration by supplying sound energy at ultrasonic frequency. The mixture is transferred in bath type sonicator and sonicated for 2 hours. As the water gets heated due to sonication, it is replaced every 30 minutes during sonication.

Nanofluid stability

The nanoparticles due to their small size and very high surface to volume ratio, have Van der Waal weak interactions between particles and agglomerate. When mixed with water the nanoparticles agglomerates over time and become large structures, which settles down, thus making the nanofluid very unstable**.** The stability of nanofluid depends on various factors like concentration, pH value and temperature. For commercial use for nanofluid, the solutions must be stable for weeks under stagnant condition. To achieve this stabilization, chemical surfactants or stabilizers are added. In this study two common stabilizers, Polyvinylpyrrolidone (PVP) and Sodium dodecyl benzenesulfonate (SDBS) were tested. It was found that PVP had negative effect on stability, while SDBS stabilized nanofluid was stable up to a week.

RESULTS

CuO nanofluid of volumetric concentrations 0.25%, 0.5%, 0.75% and 1% were tested in heat exchanger for any possible heat transfer enhancement.

Since the experimental setup did not have features to control the inlet temperatures of both hot and cold fluid, predefined temperatures and hence discrete LMTD was not able to get. Hence for comparison purpose non-linear interpolated values of Nusselt number for fixed LMTD were obtained.

It was found that the convective heat transfer coefficient (h) slightly increased for same LMTD with concentration. Thus heat transfer increases with higher volumetric concentration of nanofluid. It was also seen that for low mean temperature difference, the Nusselt number decreases with nanofluid concentration. Hence the increase in thermal conductivity of nanofluid is relatively more than the increase in convective heat transfer coefficient with concentration.

Table No.1: Nusselt number of CuO nanofluid of different volume fraction for interpolated values of LMTD

S.No	LMTD	Nusselt number of nanofluid, Nu_{nf}			
		ϕ= 0.25	ϕ= 0.5	ϕ= 0.75	ϕ= 1
1	17.5	49.694	48.293	46.773	44.987
2	19	46.461	45.353	44.493	42.953
3	20.5	43.228	42.413	42.214	40.919
4	22	39.995	39.735	39.473	38.886
5	23.5	37.655	37.133	36.762	36.852
6	25	35.376	34.819	33.529	33.593

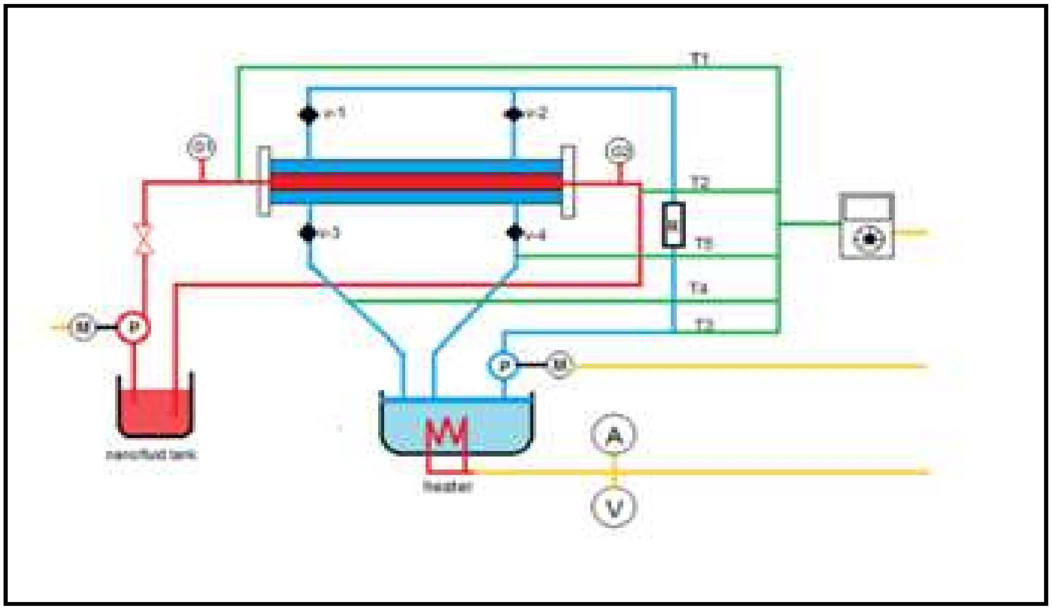

Figure No.1: Schematic diagram of the experimental setup

Figure No.2: Nanofluid samples (1% at the left and 0.25 % at right side)

Figure No.3: PVP (left) and SDBS (right) stabilized nanofluid after 1 week

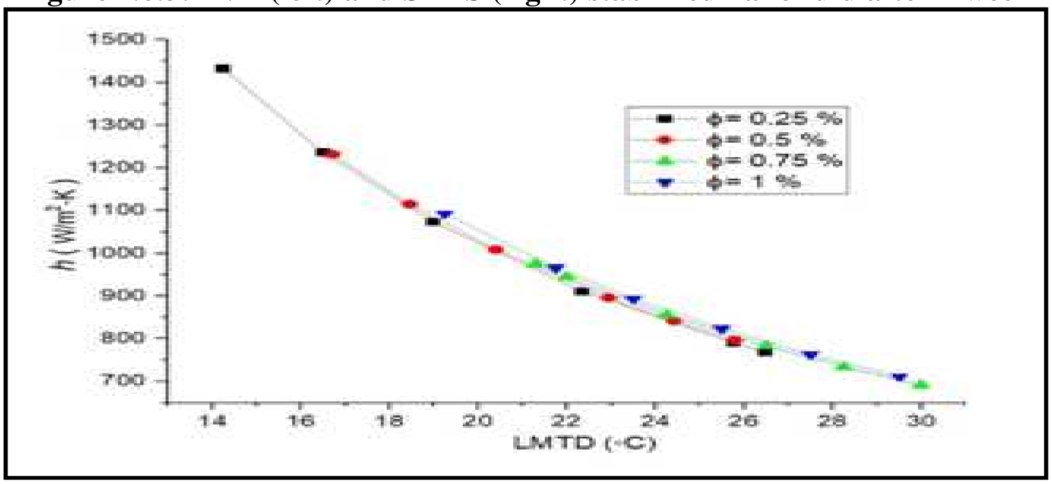

Figure No.4: Variation of Heat transfer coefficient with LMTD for different volume fraction of CuO nanofluid

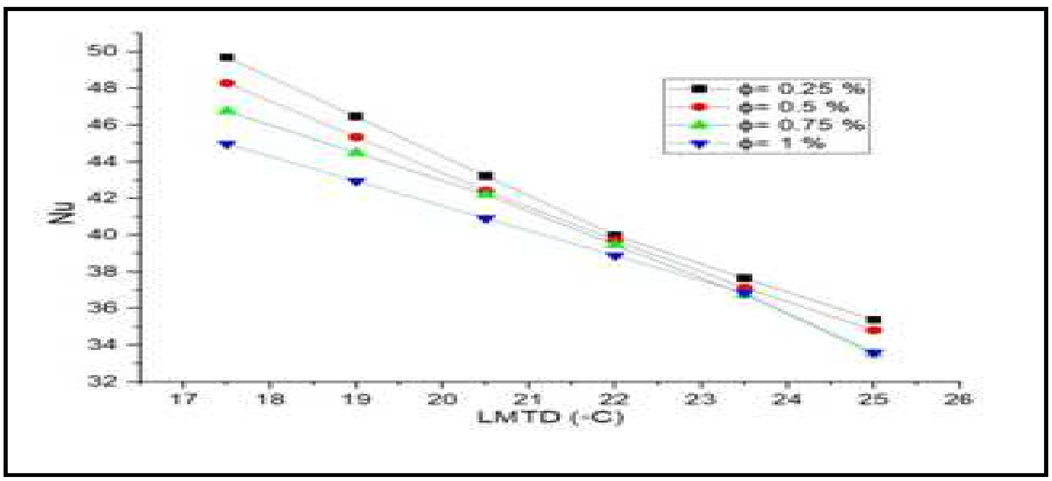

Figure No.5: Variation of Nusselt number with LMTD for different concentration of CuO nanofluid

CONCLUSION

The addition of CuO with water increases the Nusslet number about 10% for lower and higher LMTD value. The heat transfer coefficient is increased to new value for higher volume fraction of CuO and it is stagnated to lower value for other volume fractions.

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CONFLICT OF INTEREST
We declare that we have no conflict of interest.

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