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Impact of different volume concentrations and flow rates on the thermal performance of counter flow cylindrical shell and helical coil heat exchanger using Cu/H_2O nano fluids

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Abstract - *Laminar flow convective heat transfer and pressure drop characteristics of Cu-water nanofluids at low temperatures (30-70°C) in counterflow shell and helical coil heat exchanger (SHCHE) are experimentally investigated. Further experiments are carried out using natural water with the same setoff parameters. Experiments are also conducted with volume concentrations of 0.01–0.06 vol % and the Reynolds number varies between 700 to 2100. The heat transfer rate is increased by using 0.06 vol. % Cu/water single fluid with high flow rate on the shell side in the helical coil counter flow heat exchanger. The average Nusselt number increased with increasing Re number and particle concentrations. The experimental study shows that the maximum thermal performance in Copper/water single is about 14% higher than that of distilled water.*

Keywords — *Helical coil Heat Exchanger, Nanofluids, Volume Concentrations, Flow Rates, convective heat transfer;*

I. INTRODUCTION

In most industries, the concentration is on the design and thermal evaluation of heat exchangers to attain maximal heat transfer. The passive enhancement technique significantly enhances heat transfer by developing secondary flow heat transfer in a helical coil tube. [1]. several techniques were adopted [2, 3] to inflate the heat transfer rate to reduce the SHCHE and operating cost size. In this new era, Nanofluids are most vitally used in heat exchange applications due to their potential usage in enhancing heat transfer rate [4,5]. Nanofluids are introduced as the nanoparticles, where base fluid as water, ethylene glycol, or oil in counter flow heat exchangers because of higher heat transfer rate. Common nanoparticles, such as Copper Oxide (CuO), Aluminium Oxide (Al_2O_3), Titanium dioxide (TiO_2), Silicon dioxide(SiO_2), Iron oxide (Fe_3O_4), Carbon nanotube (CNT), etc. while common base fluids are water, ethylene glycol, and oil.

C_p	Specific heat (J kg^{-1} K^{-1})
ΔP	Axial pressure drop
D	Diameter of the coil (m)
ρ	Density (kg m^{-3})
d	Inside diameter of the tube (m)
μ	Dynamic viscosity (Pas)
f	Friction factor
η	Thermal performance factor
L	Length of the tube (m)
T	Temperature (°C)
Re	Reynolds number
Nu	Nusselt number
bf	Base fluid
m	Mass flow rate (kg s^{-1})
N	Number of coil turns
Subscripts	
C	coil tube
exp	experimental
nf	nanofluid
th	theoretical

A. Parameters influence the heat transfer rate

Amith Kumar Puttewar et al. [6] focused on the design of SHCHE and its thermal evaluation with counterflow configuration. The copper helical coil is used due to high thermal conductivity in insulated shells to reduce heat loss. Swapnil Ahire et al. [11] investigated heat transfer enhancement methods and variation of dimensionless numbers i.e.Re, Nu, and De. Passive enhancement techniques, Active techniques, and Compound methods are used to increase the heat transfer rate. It is evident that the heat transfer coefficient increases with an increase in Re as Nu increases. Su Thet Mon Than et al. [8] introduced a Mat Lab for mathematical calculation for a compact design of SHCHE majorly on the liquid to the liquid heat exchanger. Gafurama James et al. [9] explored the design and manufacturing of SHCHE with different pitch and curvature ratios for both parallel and counter flow configuration. The effect of pitch ratio (p/d_0) of the coil tube affects Nusselt Number (Nu_m), and a higher value of Nu_m can be achieved with a small value of p/d_0. While the lower value of Nu_m can be achieved with the high value of p/d_0 at the same D/d0, it will increase the heat transfer rate compared to its shell-and-tube heat exchanger.

H.R. Allahyar et.al [10].experimentally investigated the Heat transfer rate and ΔP on the tube side when Reynolds number is less than 2100 using a hybrid nanofluid, i.e., alumina–silver nanocomposite. The results show that the better enhancement of the heat transfer rate can be acquired by a rise in vol% of nanoparticles.

In this work, laminar flow convective heat transfer and pressure drop characteristics of Cu-water nanofluids at low temperatures (30-70ºC) in a counter flow heat exchanger are experimentally investigated. For comparative study, experiments are conducted on the coil side using natural water for the same setoff parameters. Experiments are also conducted with volume concentrations of 0.01–0.06 vol % and the Reynolds number varies between 700 to 2100.

II. EXPERIMENTAL SETUP AND PROCEDURE

The process diagram is shown in the Fg1. The system is consisting of reservoirs with a capacity of 50L for cold and hot fluids. For measuring pressure, drop pressure gauges are employed at the inlet and outlet on the coil side (cold water) when nanofluid flow in the counter flow direction. Two flow meters are placed on the shell and another coil side to vary the counterflow heat exchanger. The radiator fan is attached at the end of the cold fluid outlet to maintain constant inlet temperature. To measure the temperature variations, a sensitive infrared thermometer is used. The physical properties of the copper and aluminum coil are furnished in Table 1.In this experiment i Fig 2. Experimental setup in lab investigation Cu/H_2O nanoparticle with an average size of 112 nm of purity 99% and distilled water has been used as a cold fluid on the coil side. Fig 2 shows the XRD image of nanoparticles dispersed in distilled water. Among so many preparation methods for nanoparticle preparation, one of the best methods is the Sol-gel method. In this method, nanoparticles are prepared with high purity. Nanofluid is ready by using a two-step approach for experimentation.

To limit nanoparticle agitation and sedimentation after a two-step approach, surface treatment is carried to stabilize the nanoparticles to reduce agglomeration while performing the experimentation.

The experiments are conducted on a counterflow heat exchanger with 0.02 vol% to 0.06 vol% on the coil side (cold side) with base fluid as distilled water. Reynolds number (Re) varies from 500 to 2100 (laminar flow). The coil's material is changed and experimented with the same set of parameters for comparative study.

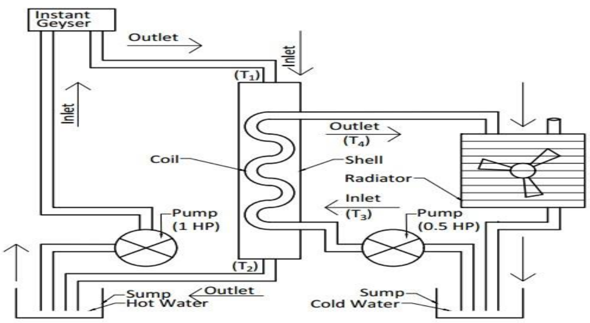

Fig 1.Scamatic diagram of counterflow shell and helical- coil heat exchanger

Fig 2. Experimental set up in the lab

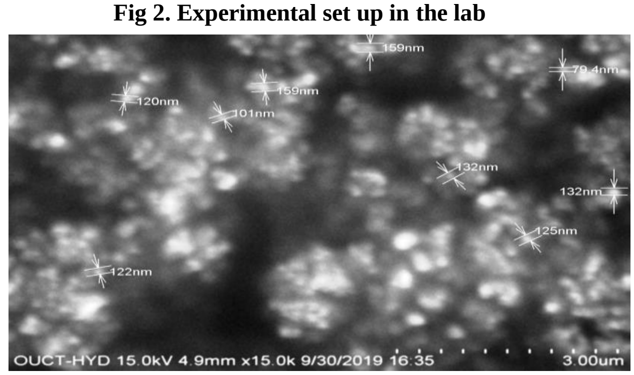

Fig 3.XRD image of Cu nanoparticles

Table 1

Geometrical parameters of a helical coil (mm)

Tube	d	t	L	D	N
Copper	12.7	1	340	95	10
Aluminum	12.7	1	340	112	10

Table 2

Comparison of thermophysical properties of the water and Cu- H_2O nanofluid

	ρ	C_p	k	μ	Pr
H_2O	998.000	4182.000	0.6	0.001002	7.0000
0.02 Vol% Cu- H_2O	1140.452	4168.0856	0.651	0.001130	7.6851
0.03 Vol% Cu- H_2O	1155.807	4156.4567	0.684	0.001235	8.8945
0.04 Vol% Cu- H_2O	1165..524	4124.1587	0.694	0.001358	12.6587
0.05 Vol% Cu- H_2O	1278.358	4095.0254	0.725	0.001485	14.5838
0.06 Vol% Cu- H_2O	1286.854	4074.4682	0.745	0.001585	15.6895

The total system is ready for experimentation after calibrating with distilled water at different flow rates. After calibration, experiments are conducted using Cu/water for a different set of parameters and concentrations. The pressure and inlet and outlet temperature are tabulated for further analysis once the temperature reaches the saturation point. Experiments are carried thrice for every set of parameters to get accurate and true values. Table 2 employed the data of the thermophysical properties of water and Cu-water at different concentrations.

III. RESULTS AND DISCUSSION

The investigations are conducted with different concentrations under laminar flow conditions in cylindrical and HCHE. Fig 3 the Nu of nanofluid versus Re in the helical copper tube for water and varying concentrations of Cu/H2O single fluid. The observations are shown that the increase in Nu is increased with an increase in vol% and Reynolds number.

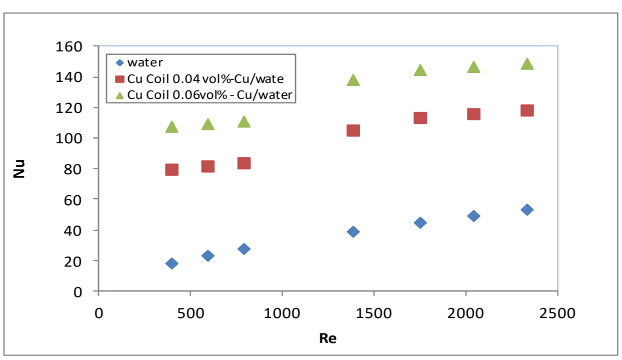

Fig 4.Nu Vs. Re different concentrations of copper coil

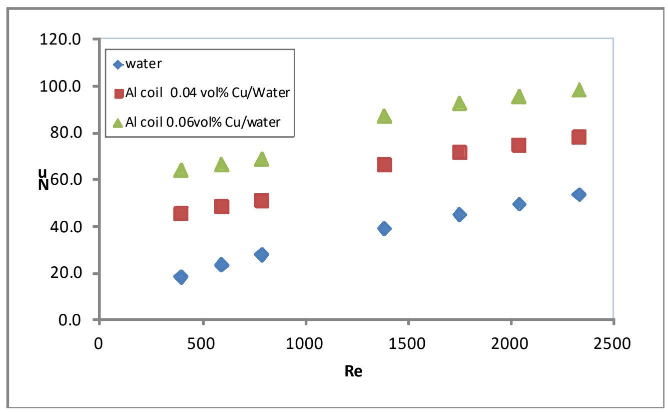

Fig 5.Nu Vs. Re at different concentrations of Aluminum coil

Firstly the temperature of the wall rises further—the temperature of the nanofluid increases. Because of the copper coil fixed inside the shell, the centrifugal force and secondary flow are developed. As a result of this, the Boundary layer's thickness is decreased, and the nanoparticles' heat is absorbed. Thus the heat transfer from the wall to the Nanao particles enhances Nu with increasing in Re. Mainly overall heat transfer increases with the Uniform distribution of the nanoparticles that can be achieved after sonication for high flow rates. Fig 3 the use of Cu/water with copper coil increased the Nusselt number at high concentration. The Nusselt number is increased 28.7% higher than natural fluid (distill water) at 0.04 vol% of Reynolds number 2100, and it shows 44.4% at 0.06 vol% of nanofluid of Re is 2100.

According to Fig 4, the aluminum coil with Cu/water shows less Nusselt number than the copper coil with the Cu/water nanofluid and the same set of parameters.

It gives a 7.1% lesser Nu value at 0.04 vol%. Similarly 6.66% less Nu at 0.06vol% about 2100 Re. The study shows that the heat transfer rate is more in copper coils than the aluminum foil. With increasing nanoparticles size and Re, the physical properties of the nanofluid changes consistently.

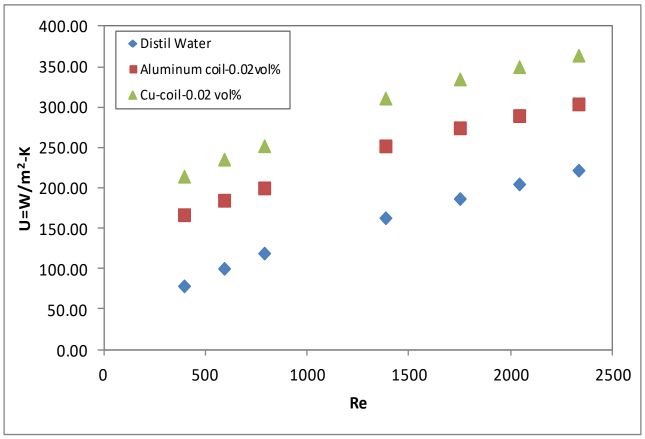

Fig 6. U Vs. Re of the copper coil and aluminum coil

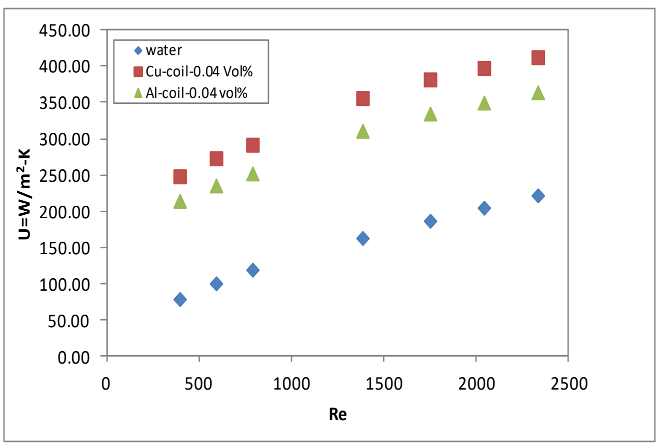

Fig 7. U Vs. Re of the copper coil and aluminum coil

When Cu/water nanofluid with 0.02vol%, 0.04 vol% and 0.06vol% are used in Fig 5, Fig 6 and Fig7. For comparative study, the same concentrations are used in copper and aluminum coils. Overall, the heat transfer coefficient is increased compared to water and Cu/water nanofluid with 0.02vol%, 0.04 vol%, and 0.06vol% of different coils, as shown in the figures. As observed from the figures, in the heat exchanger, when using a copper coil with 0.02 vol% nanofluid, the increase of between 6.5% to 8.33% is obtained in the overall heat transfer coefficient, while using 0.04vol% and 0.06vol% in aluminum and copper coils with the same set of parameters an increase of between 7.1% and 6.66, 5.66 and 8.35% is obtained in the overall heat transfer coefficient compared to aluminum and copper coils.

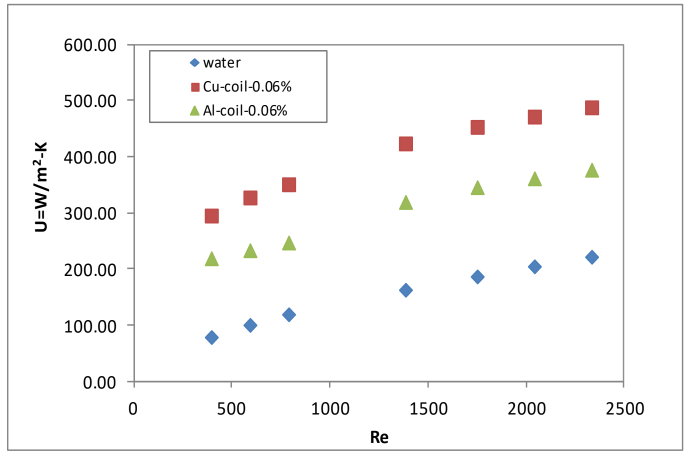

Fig 8. U Vs. Re of the copper coil and aluminum coil

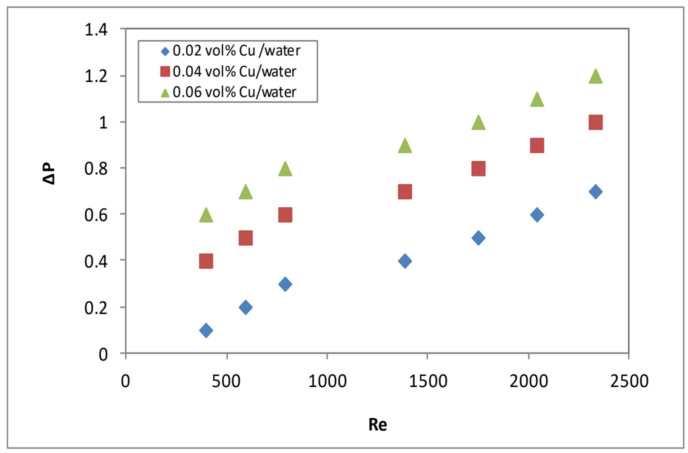

Fig 9. ΔP Vs. Re for various volume concentrations

In Fig 8, the variation in delta ΔP for different Cu/water volume concentrations is presented. From the evaluation, it is proven that pressure drop decrease with a decrease in Re. The circular nanoparticle movement near the coil's wall curvature at high flow rates boundary layer becomes thick, and the heat exchange rate between the wall and the nanoparticles increases. In secondary flow, the rate of heat transfer increased with a decrease in ΔP.

IV. CONCLUSIONS

In this research, the experiments are conducted to study laminar flow (Re >2300) convective heat transfer on SHCHE with different volume concentrations varying from 0.02 vol% to 0.06% for different flow rates. The material (Copper and Aluminium) of a coil is varied for the same set of parameters to study the thermal performance and ΔP. Based on experimental data, evaluating graphs are plotted for non-dimensional numbers (i.e., Nu and Re), ΔP Vs. Re and U Vs. Re. From the experimental study, the following observations are made.

- Copper coils show a high heat transfer rate compared to aluminium coil with a decreasing mass flow rate and increasing in vol% of the Cu/H_2O at 0.06 vol% on the cold fluid side. It is contrary to the shell side.
- When '**Re**' increases, '**Nu**' is also an increase, further heat transfer rate increases with considerable variation compared to distilled water.
- '**∆P**' is increased with increasing in '**Re**'; Because of this phenomenon, the rate of heat transfer is decreased.
- 'U' increased with an increase in '**Re.**' Because of the increase in '**U**' thermal performance, the SHCHE increased.

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