Experimental Investigations on Cylindrical Shell and Helical Coil Heat Exchanger by Varying Pitch, Flow Rate and Volume Concentration under Turbulent Flow Conditions to Enhance Heat Transfer Rate

D.Sarath Chandra[1], Omprakash Hebbal [2], K.Vijaya kumar Reddy[3]

[1]Ph.D scholar, Department of mechanical Engineering, VTU- Belagavi, Karnataka, India
[2]Professor, Department of Mechanical Engineering, PDA college of Engineering, Kalaburagi Karnataka, India
[3]Professor, Department of Mechanical Engineering, JNTU- Hyderabad, India

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Abstract - *The effect of coil pitch, flow rate and volume concentration on heat transfer rate in copper coil is studied experimentally. Experiments are performed with 0.02,0.04 and 0.06 % Vol, Pitch (p)=0.032,0.042 and 0.052m and Re in between 2400 to 16000. The pressure drop is also taken into consideration for enhancement of heat transfer. The Cu-Ni-water hybrid nanofluid is the working fluid in counter flow helical coil heat exchanger. The two-step approach is followed for adding of Cu-Ni nanoparticles in distilled water. An Ultrasonication followed by magnetic stirrer method is used for mixing of nanoparticles to enhance heat transfer rate by improving the stability of nanoparticles in base fluids. From the experimentations the maximum heat transfer is attained with Cu-Ni-H_2O of 0.06% Vol and 0.052m pitch due to its consistency in maintaining a constant temperature.*

***Key Words*: Heat transfer, Hybrid nanofluids, Turbulent flow, pressure drop ,Volume concentration and mass flow rate.**

1.INTRODUCTION

Helical coil heat exchangers are having high significance in many areas such as bioprocess industries, manufacturing sectors, making of ice creams, juices, pharmaceutical industries etc. Hence, the using of high-performance heat exchangers with maximum heat transfer are most is very important for preserving food and energy saving. Several heat transfer enhancement techniques have been applied to reduce the size of the heat exchanger. Among them utilization of nanofluids coil inserts, and are considered as best suitable methods for improving heat transfer [1-2]

The Turbulent forced convection heat transfer and pressure drop characteristics of Al_2O_3-water nanofluids in a concentric tube heat exchanger with and without wire coil turbulators were computed [3]. It was observed that the Reynolds number and the pressure drop of the Al_2O_3-water nanofluid was almost equal to that of water. It was evident that the total heat transfer enhancement, the use of wire coils was suitable for heat transfer applications.

Experiments were conducted on shell and helical coil heat exchanger for 0.05,0.1,0.15 and 0.25 volume concentration of SiO_2-water nanofluid of 17nm particle size to improve the heat transfer coefficient [4]. The Wilson plots technique was used to estimate the heat transfer coefficient of in coil tube. The investigations were carried by keeping constant flow on shell side. The results showed that the heat transfer coefficient was increased with increase in the mass flow rate and particle concentration in SiO_2-water nanofluid. The Heat transfer coefficient was increases about 28.71% when compared to distilled water.

Overall heat transfer coefficient and drop in pressure characteristics with CuO-water single type nanofluid were studied experimentally in a horizontal coil tube under constant heat flux by wire inserted tube' [3-4]. An Ultrasonic device was used for nanofluid preparation. Two different correlations were developed to evaluate heat transfer rate in heat exchanger [5]. A new CFD simulation model was used to develop heat transfer coefficient correlation for helical coil heat exchanger [6]. The results were evident that, the coil inserts with maximum diameter when showed the better performance with increase in Reynolds Number of nanofluids inside the coil tube.

The major problem agglomeration was observed in nanofluids. To improve the stability of nanoparticles a various preparation method was suggested [7]. From the results revealed that an ultrasonifiation was the best technique to eliminate agglomeration. Hielscher Brand UP 200S ultrasonicator was utilized to inhibit accumulation during study of convective heat transfer. They experimentally found that the overall heat transfer rate was enhanced with nanofluids.

Thermal performance of double pipe heat exchanger with loaded Al_2O_3-TiO_2 hybrid nanofluid in turbulent flow regimes was studied experimentally and evaluated through exergy analysis [8]. To obtain the exergy efficiency of the nanofluid-loaded double pipe heat exchanger a complete factorial experimental design approach was commissioned. It was concluded that applying nanofluids and twisted tapes boots up the exergy efficiency in comparison to utilizing conventional water as a heat transfer fluid. It was observed that increase in volume concentration, the Reynolds number increased. But this momentum exchange brings about higher axial pressure drop of the flow inside the tube.

To study the impact of fluid flow and geometrical parameters on heat transfer rate in shell and coiled tube heat exchangers experiments were performed with different coil diameter, coil pitch and mass flow rate was [9]. Tube and shell side heat transfer coefficients were determined using Wilson plots. It was evident that the higher coil diameter, coil pitch and low mass flow rate in shell and tube can enhance the heat transfer rate.

The investigations were carried out to study the effect of Pe, particle mass fraction and type of nanoparticle on the heat transfer [10-11]. It results in enhanced heat transfer rate with rise in Peclet number considerably. The heat transfer rate and the pressure drop characteristics of double tube helical coil heat exchanger was inspected by using CuO-water and TiO_2-water single type nanofluids under laminar flow conditions [12]. It is evident that the overall heat transfer coefficient of single type nanofluids and water enhanced with increase in flow rate and De.

The heat transfer behavior of aqueous TiO_2 nanofluids flowing through a straight vertical pipe under both the laminar and turbulent flow conditions were studied [13]. Further investigated the impact of nanoparticles concentrations, particle size and Reynolds number on heat transfer rate. From the investigation it was concluded that the viscosity increased with increase in particle concentration in both laminar and turbulent flow regime. The convective heat transfer coefficient was not depended on the average particle size under the conditions of this work. The results also showed that the pressure drop of the nanofluid flow was very close to that of the base liquid flow for a given Reynolds number.

In this research work, heat transfer coefficients on coil side in counter flow shell and helical coil heat exchanger with Cu-Ni-water hybrid nanofluids were studied. Also investigated the impact of coil pitch, flow rate and pressure drop on heat transfer experimentally.

Nomenclature

C_p	Specific heat (J Kg^{-1} K^{-1})
ΔP	Axial pressure drop (kg/cm^2)
D	Diameter of the coil (mm)
d	Diameter of the tube (mm)
A	area of the tube (m^2)
L	Length the tube (mm)
N	Number of turns
m	Mass flow rate (kg/sec)
Nu	Nusselt number
Re	Reynolds number
T	temperature (°C)
ρ	Density (kg/$m^{3)}$
μ	Dynamic viscosity (Pa-s)
h	Heat transfer coefficient (W/m^2 k)
U	Overall heat transfer coefficient (W/m^2 k)
t	thickness of coil tube (mm)

Subscripts

c	coil
exp	Experimental
bf	Base fluid
nf	Nanofluid
th	theoretical

2. EXPERIMENTAL INVESTIGATION

2.1 Experimental system

A new experimental setup of counter flow copper coil heat exchanger was shown in the Fig 1. It is equipped with instant geyser (3l), electric pumps (0.5 H.P and 1H.P), flow meters (20LPM), pressure gauges (5bar), and radiator fans.

Fig 1. Experimental set up in laboratory

The Cu and Ni nanoparticles are prepared by using Sol-gel method [7]. In this method nanoparticles are prepared with high purity. The SEM process is utilized for finding particle size of Cu and Ni nano particles. Two-step approach is adopted for preparing Cu-Ni-H_2O hybrid nanofluid with nominal sizes of 112 nm and Ni 102 nm. The prepared nanoparticles are surfaces treated to improve the stability when they suspended in distilled water. The total preparation of nanoparticles and surface treatment and finding of physical properties are carried at Nano wings manufacturing company.

Table 1.
Geometrical parameters of helical copper tube (mm)

coil	$d_{(tube)}$	$t_{(coil)}$	$L_{(hex)}$	$D_{(coil)}$	$N_{(coil)}$
copper	12.7	1	340	112	10

Experiments are performed on SHCHE with Cu-Ni-H_2O_2 hybrid nanofluid for 0.02,0.04 and 0.06 volume concentrations and geometrical parameters of copper coil under Turbulent flow regime. For comparative study with base fluid, experiments are repeated for same set of parameters. The data is collected for further analysis when the system is at saturation state. Different correlations and LMTD method are used for modeling and data processing.

2.2Modeling section

The density of a hybrid (Cu-Ni/water) nanofluid is calculated by using equation (1).

$$\rho_{nf} = \varphi\, \rho_{np} + (1-\varphi)\, \rho_{bf} \quad (1)$$

By using equation (2), specific heat of Cu- Ni/water hybrid nanofluid is calculated.

$$(\rho\, C_p)_{nf} = \varphi\, (\rho\, C_p)_{np} + (1-\varphi)\, (\rho\, C_p)_{bf} \quad (2)$$

2.3 Data analysis

The external surface of the copper coil is insulated to prevent the loss of heat due to contact with outside atmosphere. Hence, the heat taken by the nanofluids is equal to heat transferred by the hot water.

$$Q_{nf} = CP_{nf}\, m_{nf.}\, (T_{out,nf} - T_{in,nf}) \quad (3)$$

$$Q_{w} = CP_{w}\, m_{w}\, (T_{out,w} - T_{in,w}) \quad (4)$$

Using the following equations, average and overall heat transfer coefficients are calculated for water and hybrid nanofluid.

$$Q_{avg} = \frac{Q_{w} + Q}{2} \quad (6)$$

$$Q_{ove} = UA_i\Delta T_{lm} \quad (7)$$

Internal surface area of copper coil is calculated by using the equation (8), temperature differences at hot and cold side are calculated with the equations (9 (i)) and (9(ii)). Logarithmic mean temperature difference is calculated using equation (10)

$$A_i = \Pi D_i L \quad (8) \qquad \Delta T_1 = \Delta T_{h,i} - \Delta T_{c,o} \quad 9\ (i)$$

$$\Delta T_2 = \Delta T_{h,o} - \Delta T_{c,i} \quad 9(ii) \qquad \Delta T_{lm} = \frac{\Delta T_2 - \Delta T_1}{\Delta T_2/\Delta T_1} \quad (10)$$

Heat transfer coefficient (h) and friction factor (f) are calculated by equation (11) and (12)

$$h(exp) = \frac{m.c_{p.}(T_{h1} - T_{h2})}{A.(T_{w} - T_{h})_{M}} \quad (11)$$

$$f = 0.316\ Re^{-0.25} \quad (12)$$

Reynolds number (Re) and Prandtl number (Pr) are the important parameter to describe the fluid flow. They are calculated by using the following equations.

$$Re = \rho.U.d/\mu \quad (13) \qquad Pr = C_p\,.\,\mu/k \quad (14)$$

Nusselt number is calculated by using equation (15) for SHCHE to estimate the optimal value where we will get better heat transfer

$$Nu_c = 0.023.\,(f.\,Re^{0.8}\,.\,Pr^{0.3}) \quad (15)$$

3. RESULTS AND DISCUSSION

The results for Cu-Ni-water hybrid nanaofluid of 0.02,0.04 and 0.06 %Vol were compared with pure water under turbulent flow conditions. The process is carried at constant wall temperature. The variation in Nusselt number with respect to Reynolds number was shown in From the Fig.2 to Fig.4 shows. It was observed that the Nusselt number is increased with increase in mass flow rate and volume concentration. The maximum Nusselt number was obtained for 12 turns at 0.06 % concentration when compared to 8 and 10 turns with 0.02 ,0.04 % vol and pure water. The amount of Nusselt number is increased by 52.92%. This is due to decrease in pitch and increase in flow rate.

The Reynolds number (Re) verses Overall heat transfer coefficient for 8, 10 and 12 turns of copper coil is shown from Fig.5 to Fig.7. It is observed that the overall heat transfer coefficient is improved with rise in Reynolds number. Because at turbulent flow, distribution of Cu -Ni nanoparticles in distilled water strengthen the hesitation of particles and there by the heat transfer rate increases. It is also evident that the heat transfer coefficient is more in case of copper coil with 12 turns and volume concentration of 0.06%. Here pressure drop is same as the increase in heat transfer rate. At 2800 < Re < 29000, the overall heat transfer coefficient is increased by 38.37, 58.06 and 64.70% for 0.02, 0.04 and 0.06 %Vol respectively compared to pure water.

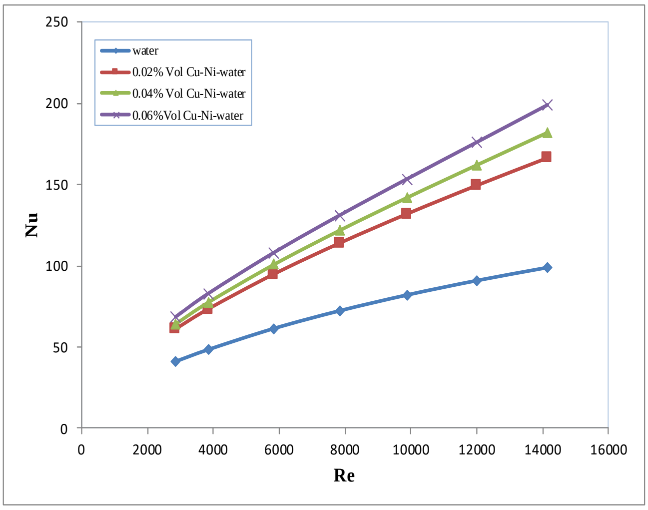

Fig 2. Re Vs Nu for 8 turn copper coil

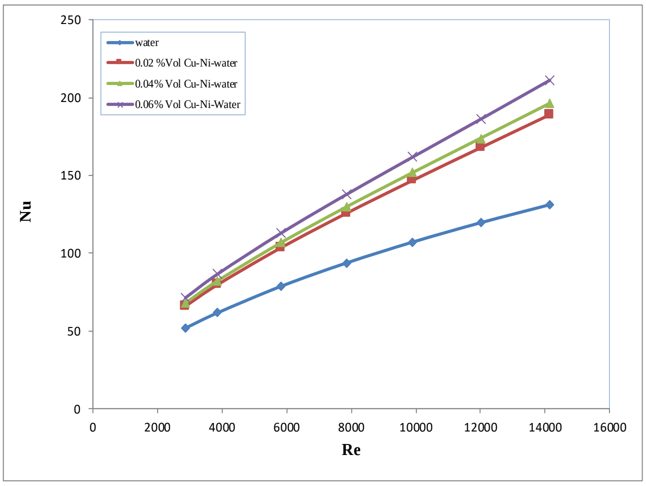

Fig 3. Re Vs Nu for 10 turn copper coil

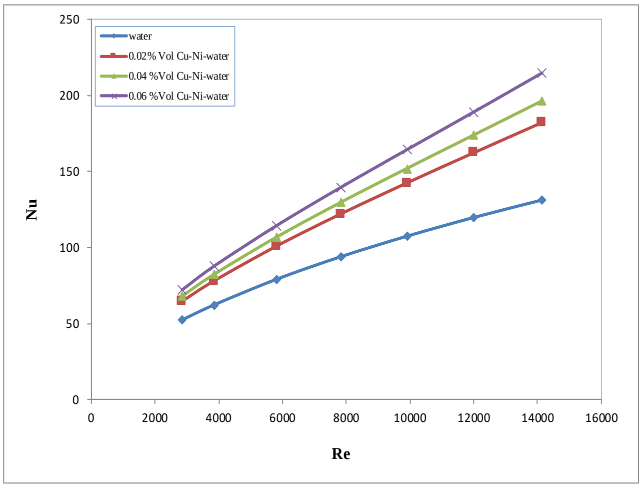

Fig 4. Re Vs Nu for 12 turn copper coil

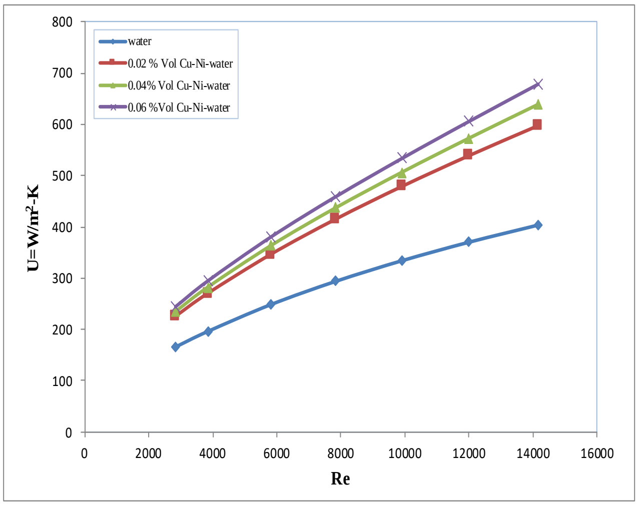

Fig 5. Re Vs U for 8 turn copper coil

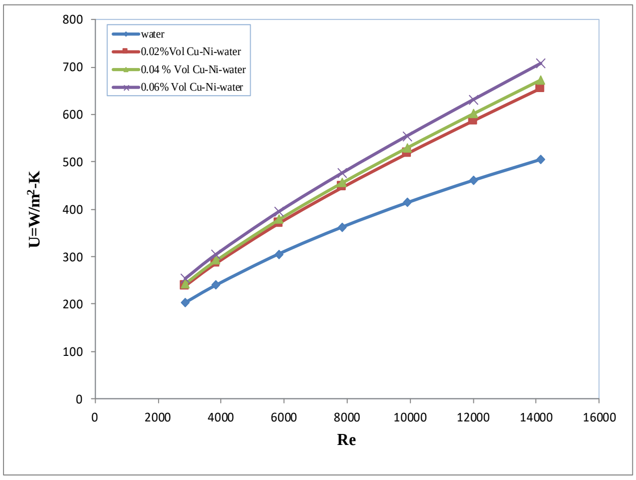

Fig 6. Re Vs U for 10 turn copper coil

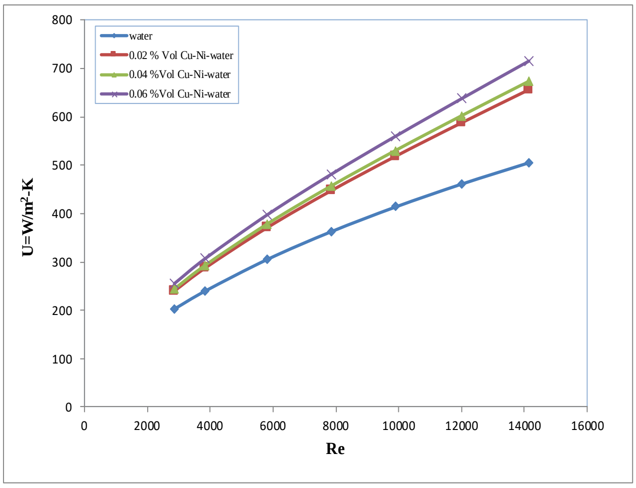

Fig 7. Re Vs U for 12turn copper coil

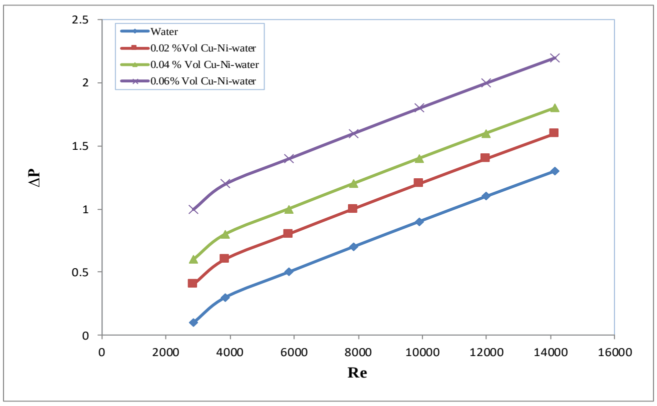

Fig 8. Re Vs ΔP for 8 turn copper coil

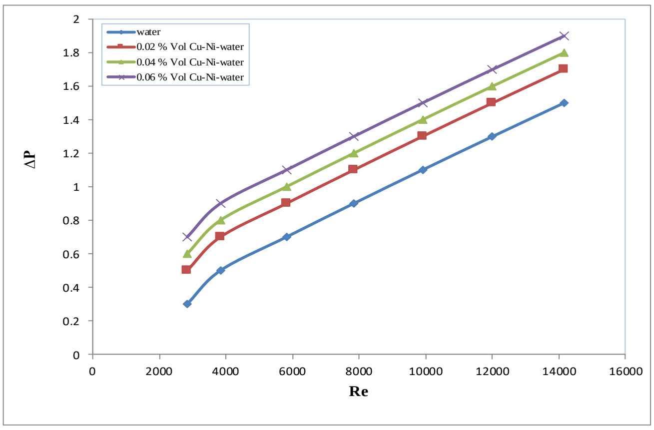

Fig 9. Re Vs ΔP for 10 turn copper coil

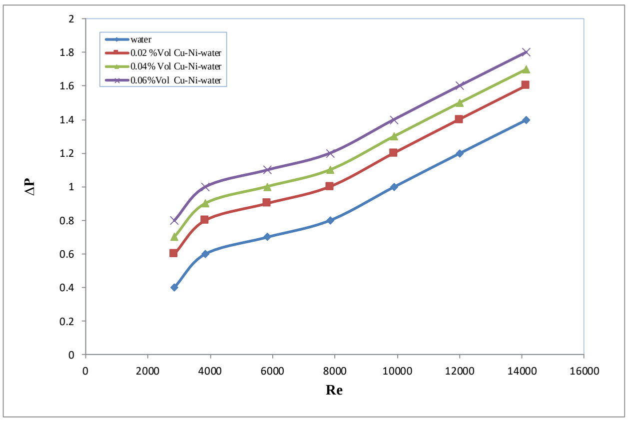

Fig 10. Re Vs ΔP for 12 turn copper coil

The change in pressure drop for Re >29000 is shown in Fig.8 to Fig.10 distilled water. It was evident that ΔP and Re increased with increase in flow rate, flow direction and concentration in helical coil heat exchanger. This is due to high density of Ni and Cu and due to Brownian movement of nanoparticles leads to improve the energy transmission between the Cu- Ni-nanoparticles particularly near the coil inner wall and hence the axial pressure drop is increased. The maximum pressure drop was observed in case of copper coil with 12 turns and concentration of 0.06%Vol. But in this case variation is stable because of high flow rates.

4.CONCLUSIONS

Detailed investigation is carried out on the counter flow shell and helical copper coil heat exchanger with hybrid (Cu-Ni/water) nanofluid. The experiments are staged at constant wall temperature. From the results following observations are made

- Experiments are conducted on SHCHE for Re =2400 to 16000 with 8, 10 and 12 turns by varying particle concentrations. The overall heat transfer is increased by 34.37, 48.06 and 54.70% compared to distilled water. This is due to rise in mass fraction and mass flow rate.
- The Nu on coil side is improved with increase in volume concentration and number of turns of copper coil. But Cu-Ni-water hybrid nanaofluid with 0.06%vol shown the best results with less pressure drop and constant variation in heat transfer from hot end to cold end.
- The Nusselt number of SHCHE using Cu-Ni/water for 0.02, 0.04 and 0.06% volume of nanofluids increased by 26.62, 47.61 and 58.00% when compared with distilled water. This is because of increase in curvature radius of helical coil.
- It is observed that the pressure drop is increased by 50% in Cu-Ni/water at 0.06%volume with 12 turns compared to distilled water. This is due to increase in number of turns and nanoparticle sedimentation.
- The Cu-Ni/water hybrid nanofluid with 0.06% Vol at 16000 is preferable to use for low temperature applications in food processing industries with consistent heat transfer.

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BIOGRAPHIES

Ph.D. Scholar and working as Assistant professor in VNRVJIET, Hyderabad.

Area of interest: Heat transfer, Nano materials and Composite materials.