



## Investigation on performance of bio synthesized copper nano fluid in helical coil and shell type heat exchanger

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### ABSTRACT

Tulsi leaf extracts has been used to produce biosynthesized copper nanoparticles. This biosynthesized nanoparticle is used for the preparation of nanofluid. The performance of nanofluid in a helical coil heat exchanger was studied for heat transfer rate and analyzed using standard correlation at the laboratory of NIT, Raichur. The fluid inlet temperature of the coil was 60 °C and temperatures of fluid inside a shell of 32 °C were maintained. A dean number in the range of 1000 – 10,000 was set on the shell side. The inlet fluid flow was constant at the coil. Thermal analysis has been carried out considering flow rate, overall heat transfer coefficient, and inlet and outlet temperature. When compared to the base fluid, using bio-synthesized Nanoparticles improved the heat transfer coefficient.

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### 1. Introduction

Heat exchanger plays a vital role in heat transfer between fluid and fluid as well as fluid and solids. Different types of heat exchangers were available where heat transfer takes place with or with direct contact of fluid. In most thermal applications, improving heat transfer is critical. In recent years the heat exchangers have been the frontier in improving their performance and there is steady progress in improving heat transfer rate in active or passive ways. The bottleneck observed in heat exchangers i.e. lower heat transfer coefficient fluid is used in these systems. A solution to overcome this problem is replacing the conventional fluid with nanofluid. The addition of nanoparticles to fluid has been shown to enhance the fluid's heat transfer properties. Because of issues with Nano size particle suspension, different Nanoparticles have been used depending on their heat transfer application.

Choi et.al was the first to demonstrate the capabilities of this new class of nanofluids. Nanofluids are colloidal suspensions of nano-sized (5–100 nm) particles in a base liquid, according to the definition. They observed a significant increase in thermal conductivity values, which could lead to an increase in the heat trans-

fer exhibitions of the fluid stream. Since then, research has continued to document the effects of various nanoparticles in various base fluids. Khoshvaght et al. experimented with laminar flow conditions with 0.1 & 0.3 percent Cu of the copper nanoparticle has observed that enhancement in thermal performance, Reynolds number, heat transfer, and pressure drop with increasing nanoparticle concentration. T. Srinivas et. al. conducted experiments for 0.3, 0.6, 1, 1.5 & 2 percent concentration of Al<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub>, CuO/Water under Turbulent & Laminar flow condition. When comparing the three nanofluids, the 2 percent wt. CuO nanofluid had the best heat transfer. When compared to water, CuO nanofluid increases heat transfer by 32.7 percent. Milad Rakhsha et al. CuO/Water 0.10 percent concentration is used for the experimental analysis under Turbulent & Laminar flow. CuO nanofluid discovered that with centrifugal force, the higher the velocity and Nusselt number, the easier it is to reach the outer surface of the helical tubes. Vinita. et.al. analyzed the nanoparticle volume fraction profiles and concluded that the nanoparticle volume fractions decline for the value of volume concentration.

Helically coiled tubes are superior to straight tubes in a few studies. Curved tubes have been proposed as a method for improving heat transfer and are widely used in a variety of mechanical applications. We used a helical coil heat exchanger for this investi-

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### Nomenclature

A	Cross sectional area (m <sup>2</sup> /s)
S	Surface area (m <sup>2</sup> /s)
D	Coil diameter (m)
d	Tube Diameter (m)
L	Test section length (m)
V	Voltage (V)
I	Current (A)
m	Mass flow rate (kg/s)
Re	Reynolds number, $4m/(\pi\mu D)$
Pr	Prandtl number, $(\mu c_p/k)$
c <sub>p</sub>	Specific heat (J/kg K)
f	Friction factor
h	Convective heat transfer coefficient (W/m <sup>2</sup> K)
k	Thermal conductivity (W/m K)

Nu	Nusselt number, $(hD/k)$
T	Temperature (°C)
v	Fluid velocity (m/s)
Q	Heat input (W)
q	Actual heat flux (W/m <sup>2</sup> ).

#### Greek Symbols

$\Delta p$	Pressure drop (Pa)
$\mu$	Dynamic viscosity (kg/m <sup>2</sup> s)
$\rho$	Density (kg/m <sup>3</sup> )
$\phi$	Volume concentration (%).

gation. The nanofluids lead to an increased thermal conductivity and finally to a heat transfer enhancement in heat exchangers. Hence an experiment on performance of bio synthesized copper nano fluid in helical coil and shell type heat exchanger was conducted at NIT Raichur.

## 2. Experimental apparatus

The experimental setup involving two-part viz. helical coil side heat exchanger (HCSHE) and shell side of heat exchanger (SSHE). The main components of HCSHE are helical coil, hot reservoir, pump, control valve, and heater coil. The helical coil having a dimension of 130 mm and a pitch of 30 mm with 7 no of turns. The helical coil is made of the copper tube having a thickness of 1.7 mm with an outer diameter of tube 12.7 mm. The total length of the tube is 2600 mm. The insulated hot reservoir is embedded with a heater coil. The heated fluid is circulated in a helical coil through a pump for exchanger of heat transfer to fluid in the shell. The measuring instruments like rotameter (mass flow), thermocouple (temperature), U-tube Manometer (pressure) were used in the setup. The arrangement of instruments and flow direction is shown in Fig. 1. The components of SSHE are shell, Condenser, pump, and measuring instruments. The shell is made of copper having a dimension of 150 mm diameter, 250 mm height with a thickness of 10 mm. The commercial radiator of TATA ACE is used as a condenser. The hot nanofluid from the shell side is cooled in this condenser. A commercial centrifugal pump is used to pump the water from the cold reservoir to the shell of the heat exchanger. The measuring instruments used for mass flow (rotameter), temperature (thermocouple PT-100), and pressure (U-tube Manometer) were arranged as shown in the block diagram. The block



Fig. 1. Experimental setup.

diagram of Shell and helical coil heat exchanger is shown in Fig. 1. Fig. 2. Table 1. Table 2.

## 3. Preparation of nano fluid

### Broth extraction

The drying of Tulsi leaf was done using solar dryer maintained at a temperature of 40 °C for 48 h. Before drying Tulsi is thoroughly cleaned using distilled water. In a mixer, the Tulsi leaves are churned in small powder. Cryogenic ball milling reduces the powder to nanoparticles. The obtained powder is passed through a set of 20 mesh sieve (840 μm) to get a uniform size. The method of synthesis used was a top-down approach. Then the 10 g of uniformly sized powder is taken into a beaker along with 100 mL of deionized water and it is boiled at 60 °C for 15 min. The obtained solution is filtered with double filtration.

### Synthesis of copper nano particles

100 mL of 1 mM aqueous copper sulphate pentahydrate (CuSO<sub>4</sub>·5H<sub>2</sub>O) is added to 10 mL Tulasi extract with continuous stirring. The mixture is kept in incubation at 31 °C for 24 h. The color changes from light green to dark green which indicates the formation of copper nanoparticles.

To determine the thermo-physical properties of copper nanofluid, the following correlations were used.

$$\text{Thermal conductivity (Maxwell)} \quad k_{nf} = \frac{k_p + (n-1)k_w - \phi(n-1)(k_w - k_p)k_w}{k_p + (n-1)k_w + \phi(k_w - k_p)}$$

$$\text{Density (Pak and Cho)} \quad \rho_{nf} = \phi \cdot \rho_p + (1 - \phi) \cdot \rho_w$$

$$\text{Viscosity (Einstein)} \quad \mu_{nf} = \mu_w + (123\phi^2 + 7.3\phi + 1)$$

$$\text{Specific Heat (Xuan and Roetzel)} \quad (\rho C_p)_{nf} = \phi(\rho C_p)_p + (1 - \phi)(\rho C_p)_w \quad (\text{Fig. 3, Fig. 4, Fig. 5}).$$

## 4. Experimental procedure

Initially, the experiment was conducted for trail reading using DI- water on both sides of Shell and Helical coil heat exchanger. The electrical power of 240 V is supplied through dimmer stat to heating coil in the hot reservoir and controlled by a thermostat to stop the electrical supply at a set temperature of 60 °C and this temperature is measured and displayed through thermocouple and digital temperature indicator respectively. The Deionized (DI) water in a hot reservoir is maintained at this constant temperature. The DI water is also filled to the cold reservoir. The electrically operated pump of the cold and hot reservoir was used for pumping fluid in a parallel flow arrangement. The mass flow rate to the coil side of the heat exchanger is set at 160 lph by a valve and indicated by a rotameter. In a cold reservoir, DI-water is pumped to the shell side, and the required mass flow rate is set. The supply of fluid to

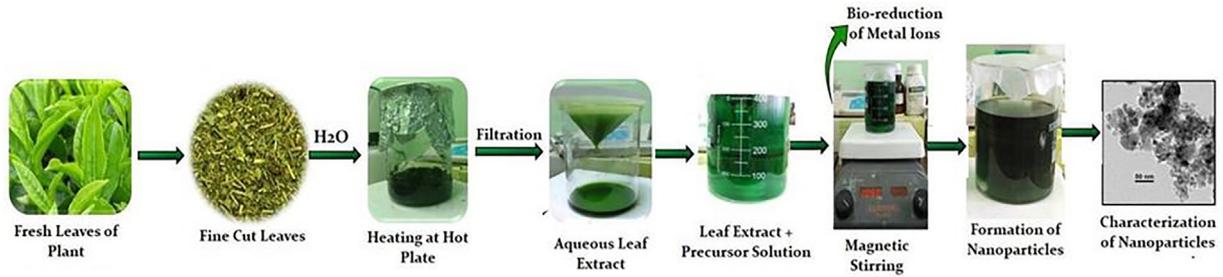


Fig. 2. Process flow chart of preparation of nanoparticle.

Table 1 Specifications of the experimental test setup.

S. No	Particular	Specifications
1.	Pump	0.5 HP
2.	Rotameter	1–12 LPM
3.	HCSHE Copper material	I.D.:- 0.0117 m, O.D.:- 0.0127 m
4.	Insulation material	Asbestos rope
5.	Reservoir	Mild steel
6.	U-tube manometer	Mercury

Table 2 Thermo-physical Properties.

Sl.No	Properties	Water	Nano particle
1	Density	997	8944
2	Dynamic Viscosity	0.00089	
3	Specific Heat	4197	387
4	Thermal Conductivity	0.61	385

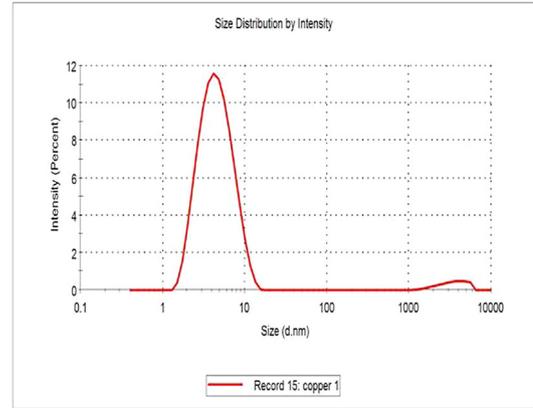


Fig. 4. Size distribution by intensity.

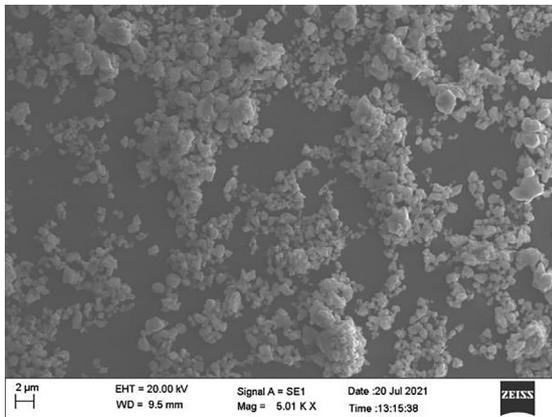


Fig. 3. SEM image of Nano particle.

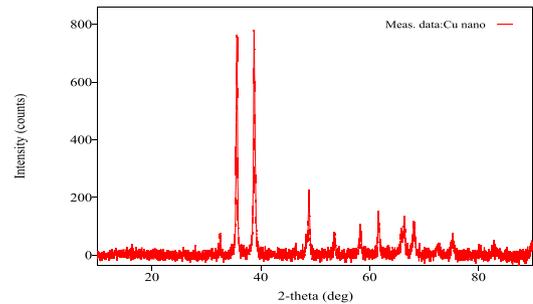


Fig. 5. XRD of copper nanoparticles.

the shell is varied from 11lpm to 12 lpm using a valve. The supply of mass flow rate was measured using a rotameter with a minimum division of 0.5lpm. The trail run readings have been noted down. Similarly, the shell side fluid has been changed to copper nanofluid. The forced convection method is used in a condenser which cools the fluid received from the outlet of the heat exchanger and cooled nanofluid from the condenser was supplied to a cold reservoir, to extract the heat from the hot fluid.

The four thermocouples (PT-100) were used to record the inlet and outlet temperatures of hot and cold fluid. The thermocouple is used to measure the wall temperature of the coil kept in the shell. A U-tube manometer is used to measure the pressures at the flow's inlet and outlet. The procedure is repeated at the cold fluid inlet for various mass flow rates.

### 5. Data reduction

The following equation have been used

$$\text{Cold water } (Q_{\text{cold}}) Q_{\text{Cold}} = m * Cp * \Delta T$$

$$\text{Hot water } (Q_{\text{Hot}}) Q_{\text{Hot}} = m * Cp * \Delta T$$

$$\text{Average heat Flow } (Q_{\text{avg}}) Q_{\text{avg}} = \frac{Q_{\text{cold}} + Q_{\text{hot}}}{2}$$

$$\text{Reynolds Number } (Re) Re = \frac{4m}{\pi d \mu}$$

$$\text{Nusselt Number } (Nu) Nu = \frac{h \cdot d}{k}$$

$$\text{Dean Number } (De) De = Re \sqrt{\frac{d}{D}}$$

$$\text{Pressure Drop } (\Delta p) \Delta p = \rho * g * h$$

$$\text{Friction Factor } (f) f = \frac{\Delta p}{(\frac{1}{2}) \rho v^2 (L/D)}$$

$$\text{Thermal Performance Factor } (\eta) \eta = \left( \frac{Nu_{nf}}{Nu_{aw}} \right) \left( \frac{f_{nf}}{f_{aw}} \right)^{-1/3} * \delta^{0.003}$$

6. Results

Laminar and turbulent flow tests were carried out with dean numbers ranging from 1000 to 10,000 when compared to the base fluid. The Figs. 6 and 7 Depicted the effect of Nusselt Number with Dean Number for various concentration volume of nanoparticle. Nusselt number increases with increase in Dean Number for various concentrations of nanoparticle (i.e. 0.01, 0.03 & 0.05% of the concentration of nanofluid). It was observed that heat transfer was enhanced with the use of biosynthesized copper nanofluids. The results revealed that Nusselt Number increases with an increase in dean number, this is due to the thermal conductivity of dispersed nanoparticles in the base fluid improves the heat transfer rate. The increased convective heat transfer rate in a tube is of swirl type and it causes disturbance near the coil surface. This causes an increase in dweller time of the nanofluid and there is an excellent fluid blending and effective redevelopment of thermal and hydrodynamic layers. The study also revealed that the improvement in dean number improves the heat transfer rate. The performance of nanofluid (biosynthesized copper nanofluid) is studied in helical coil and shell heat exchanger and compared with the DI water. The increase in mass flow rate and nanoparticle concentration has influenced the increase of the Nusselt number.

It is essential to validate the experimental set up to check the reliability of the set up. Therefore experiments were conducted with DI water in plain tube under laminar flow conditions. Constant heat flux boundary condition was maintained and the experimental results showed reasonable agreement with the David equation for laminar flows The Fig. 8 shows the comparison of experimental results in terms of Nusselt No. with Dean No for laminar flow condition with the findings of David . From Fig. 8, it was found that the deviation of the experimental set up was within  $\pm 9\%$ .

The experiments were conducted with DI water in plain tube under Turbulent flow conditions. Constant heat flux boundary condition was maintained and the experimental results showed reasonable agreement with the Roger equation for Turbulent flow. The Fig. 9 shows the comparison of experimental results in terms of Nusselt No. with Dean No for Turbulent flow condition with the findings of Roger. From Fig. 9 it was found that the deviation of the experimental set up was within  $\pm 8\%$ .

Fig. 10 shows that use of nanoparticle has a definite effect on the increase of heat transfer rate with a small change in friction factor. Because the nanofluid has a higher density than water, a pressure decrease was predicted. The pressure drop observed for the flow of Copper nanofluid was considerable, with values 5 to 6 percent higher than the pressure drop measured for water.

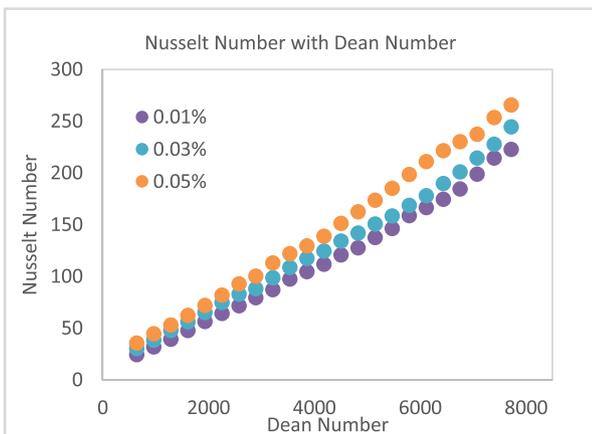


Fig. 6. . Nusselt Number with Dean Number.

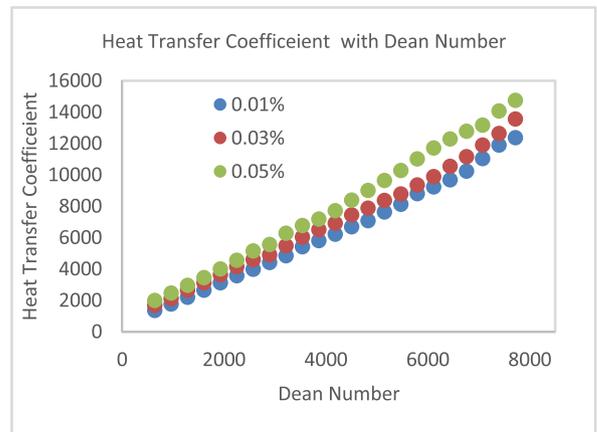


Fig. 7. Heat Transfer Coefficient with Dean Number.

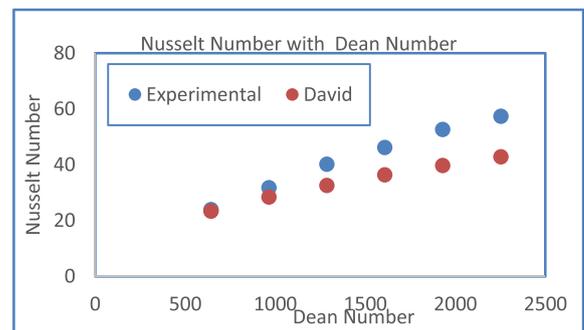


Fig. 8. Nusselt Number with Dean Number for laminar flow condition.

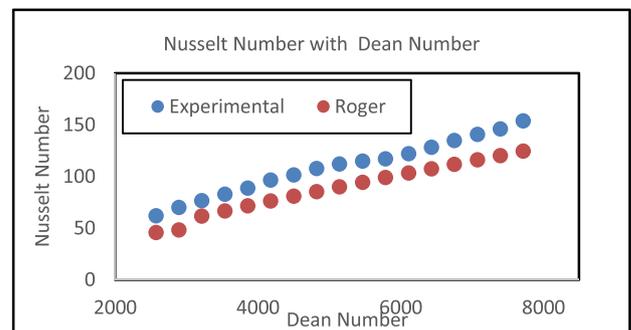


Fig. 9. Nusselt Number with Dean Number for turbulent flow condition.

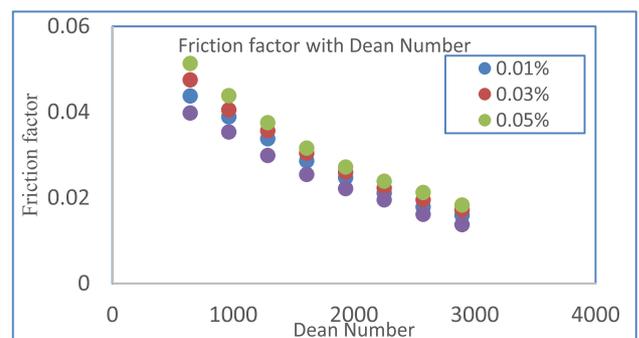


Fig. 10. Friction Factor with Dean Number for laminar flow condition.

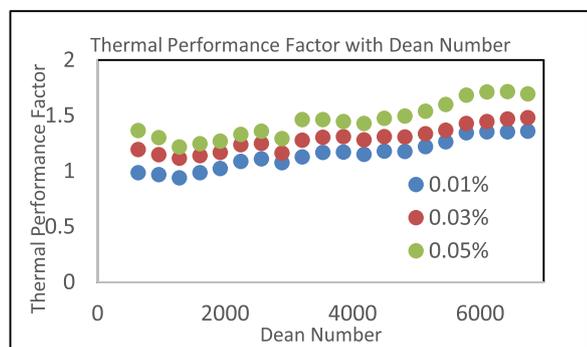


Fig. 11. Thermal Performance Factor with Dean Number.

Fig. 11 shows that at 0.05 percent volume concentration of copper/Deionized water nanofluid, the maximum thermal performance factor value the thermal performance factor is in the range of 0.8 to 1.7.

## 7. Conclusion

- The performance of heat transfer and Friction Factor characteristics were studied using copper/DI water nanofluid in an HCSHE.
- An experimental setup was validated and it was found that the setup was in agreement with the standard correlation
- Heat transfer characteristics were measured for the set up with DI water and 0.01, 0.03 & 0.05% of the concentration of nanofluid. It was observed that heat transfer was enhanced with the use of biosynthesized copper nanofluids.
- The results indicated that the use of particles has a definite effect on the increase of heat transfer rate with a small change in pressure drop.
- A pressure drop study was done and it was found that the pressure drop was only 9% more in the case of theoretical value to the experimental value.
- The thermal performance of copper/DI water nanofluid at 0.05 percent concentration is improved, according to the experimental results. The value of the thermal performance factor decreases slightly as the Dean Number increases.

### CRedit authorship contribution statement

**H. Ravi Kulkarni:** Methodology, Validation, Formal analysis, Investigation, Writing – original draft. **C. Dhanasekaran:** Project administration, Supervision. **P. Rathnakumar:** Project administration, Supervision. **Edwin Geo Varuvel:** Project administration, Supervision. **S. Sivaganesan:** Project administration, Supervision. **M. Anantachar:** Project administration, Supervision.

### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Further Reading

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