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Experimental study on thermal analysis of helical coil heat exchanger using Green synthesis silver nanofluid

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ABSTRACT

Green Synthesis of silver nano particles using Neem leaf extracts and preparation of nanofluid, heat transfer, pressure drop and friction factor for helical coil heat exchanger have been experimentally investigated and compared with the standard correlation given by various researchers is discussed in this paper. Inlet temperatures of hot water on coil side and cold water on shell side were maintained at around 58 °C and 32 °C respectively. Experiments were performed over the Dean number range on shell side is 1000 to 3000, by varying mass flow rate and Reynolds number on coil side is kept constant at 5780. Thermal analysis has been carried out by considering various parameters such as temperature, flow rate, overall heat transfer coefficient. Use of green synthesized Nano particles have shown enhancement of 32% in heat transfer coefficient compared to base fluid. Thermal performance factor has been slightly decreased with increase in concentration and is feasible to use 0.05% of concentration nanofluid.
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1. Introduction

Heat exchangers encourage the trading of heat between the liquids that are at different temperature while keeping them away from blending it with one another. These heat exchangers had become the basic necessity of the current society as they don't bring about any hurtful impacts to the situations. The expense associated with this energy extraction is additionally less and conservative Tables 1–3.

Heat transfer improvement is essential in most thermal applications. There are two strategies to improve the heat transfer rate i.e. active and passive methods Heat exchangers are a necessary segment in an assortment of modern settings, for example, cooling frameworks, power plants, treatment facilities, and in this manner consistent endeavours are made to build their heat transfer efficiencies.

In late decades while there has been consistent advancement in improving the performance of heat exchangers by tending to their development and format issues, the poor heat transfer properties of the working liquids utilized in the heat exchangers have still stayed a significant exhibition constraining element for these systems. Adding of nano particles with high thermal conductivity into these cooling liquid fluids appears to expand their abilities since solids have higher heat transfer coefficients than fluids. The advancement of littler particles, of nano-sizes, has beaten the negative hydrodynamic impacts of solid particles in the liquid. Suspension of nano-sized particles in a liquid have been seen to essentially upgrade heat transfer properties of the liquid while being skilled at neither stopping up nor settling in a heat exchanger application, basic issues related with suspension of larger size particles.

Choi and et.al. [1] Were the first to exhibit the capability of this new variety of fluids, known as nano fluids. Nano fluids by definition are colloidal suspensions of nano-sized (5–100 nm) particles in a base liquid. They watched huge upgrade in thermal conductivity esteems that might prompt an expansion in the heat transfer exhibitions of the fluid stream. From that point forward, research has kept on reporting the impacts of different nano particles in different base fluids. [4]The few examinations have demonstrated that helical coiled tubes are better than straight tubes when utilized in heat transfer applications. The centrifugal power because of the shape of the tube brings about the auxiliary stream advancement which improves the heat transfer.[2] Various examinations have been done to improve the steadiness of nanofluids and to prevent two phenomena which are basic to the stability of nanofluid, for example aggregation and sedimentation . Having this as a pri-

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Table 1
Thermo physical properties of nanofluid.

S. No	Physical Properties	Water	Nanofluid		
			0.5	1.5	2.5
1.	Thermal Conductivity (W/mk)	0.6	0.61002	0.61005	0.610091
2.	Density (kg/m^3)	997	997.091	997.2779	997.47
3.	Specific Heat (J/kgJ)	4179	4178.60	4177.78	4176.92
4.	Viscosity (kg/ms)	0.00765	0.0008	0.00081	0.00083

Table 2
Specification of Helical coil heat exchanger.

Sl. No	Dimension parameter	Dimension in m
1	Inner Diameter of coil	0.1046
2	Outer Diameter of Coil	0.13
3	Pitch	0.03
4	Inner diameter of tube	0.011
5	Outer diameter of tube	0.0127
6	Length of tube	2.6
7	Height of the shell	0.25
8	Inside diameter of shell	0.15

Table 3
Specifications of the experimental test setup.

S.No	Particular	Specification
1.	Water pump	0.5 HP
2.	Rotameter	1.2–12 LPM
3.	Test section Copper material	I.D.: 0.01 m, O.D.: 0.012 m, L = 1 m
4.	Insulation material	Asbestos rope
5.	Water tank	Mild steel
6.	U-tube manometer	Mercury

mary concern, nano liquids have pulled in the consideration of numerous researchers, especially in the field of thermal

Curved tubes have been presented as one of the heat transfer improvement methods and are broadly utilized in different mechanical applications.[3]Nanofluids are designed colloids made out of a base fluid and nano-scale particles. They have been considered in light of their upgrades in the heat transfer properties of base-liquid. He demonstrated that the expansion of a limited quantity (under 1% by volume) of nanoparticles to ordinary fluids expands the thermal conductivity of the liquid up to around two times. Use of green synthesised nanofluid would be a step to save over environment and effective utilization of resources that is available in nature.

1.1. Nanofluid preparation

Preparation of plant extracts

The Neem leaves (azadirachta indica) were collected, cleaned and washed thoroughly with distilled water. The cleaned neem leaves are dried in solar tunnel dryer at 40^{0}c for two days to remove the moisture present in leaves. The dried leaves are crushed into power using mixer of less than 180 μm. The power is reduced to nano particles in cryogenic ball milling. The synthesis method used was top down approach.

Green synthesis of silver nano particles

The extracts were mixed with 100 ml of 1 mM aqueous silver nitrate solution under continuous string. After complete mixing of leaf extracts with precursor the mixture was kept for incubation at 31^{0}c for 24 h. A change in colour from colourless to brown colour indicates that the Ag^+ to Ag^o have been reduced. Hence nanoparticles have been formed [5]. The solution has now been centrifuged at 6000 rpm for 30 min and then followed by re-dispersion of the pellets in deionized water to remove unwanted biological materials.

Green synthesized nanoparticles were used to prepare the nanofluid the properties of the nanofluid are described in the table 1.1. The morphology of nano particles are studied using Scanning electron microscope (carl Zeiss Microscopy EV10, Germany) with magnification range 1 to 30,000 times, acceleration voltage range of 0.2 to 30Kv, probe current 0.5pa to 5μA, X-ray analysis 8.5 mm AWD & 35^0 take off angle, pressure range 10 to 3000 Pa and time range of 5-60 min. SEM image show that the particles size is less than 30 nm. SEM image is taken from as the surface of nano particles are hydrophobic in nature and are prone to aggregation in absence of surfactant. Hence 1% of polyvinyl pyrolidine surfactant is used and thoroughly stirred using magnetic stirrer and ultra sonic vibrator, voltage 110/220 V, ultrasonic frequency 40 kHz, time range of 5–60 min, model -LMUC-2.8L, heating range of 5-80^{O}C, for 3 h, which ensures uniform dispersion with steady suspension of nanoparticles. The nano fluid is seemed to be stable over a period of month.

The following correlations were used to determine thermo physical properties of nanofluid

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

Density (Pak and Cho) $\rho_{nf} = \varphi.\rho_p + (1-\varphi).\rho_p$

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

Specific heat (Xuan and Roetzel) $(\rho C_p)_{nf} = \varphi(\rho C_p)_p + (1-\varphi)(\rho C_p)_w$

1.2. Experimental setup

Initially, De –ionized water is poured into hot and cold reservoir and the values are set for parallel flow arrangement. Mains are turned on and Power is supplied to both pump at hot reservoir side and pump at cold reservoir side. Power is also supplied to the heater. At hot reservoir, normal water is heated using 1500 W electrical heater. Temperature is set at 60℃ by using the thermostat. The voltage is supplied at 150 V to the heater by using a dimmer-stat. The mass flow rate is set at 160 LPH at the hot fluid inlet by using a rotameter. The temperature is being monitored by both digital temperature indicator as well as a thermometer. In cold reservoir, various types of fluids can be used for experimentation purpose. In this experiment, we used de-ionized water. The mass flow rate is varied from 1.5 LPM to 5 LPM with 0.5 LPM variations. A radiator with fan arrangement is placed near the cold reservoir. It helps in cooling down the water by forced convection method. The outlet from the radiator is placed in the cold water reservoir, so that the cooled fluid can be reused to extract heat Figs. 1-7.

Once the temperature reaches 60℃, the inlet temperature and outlet temperature of hot fluid is noted by using a thermometer. Similarly, the inlet temperature and outlet temperature of cold fluid is noted by using a thermometer. The wall temperature is obtained by using the digital temperature indicator. Pressures at Inlet and outlet flow condition are measured through u – tube manometer. The readings obtained are tabulated in a tabular column. The above procedure is repeated for different mass flow rate

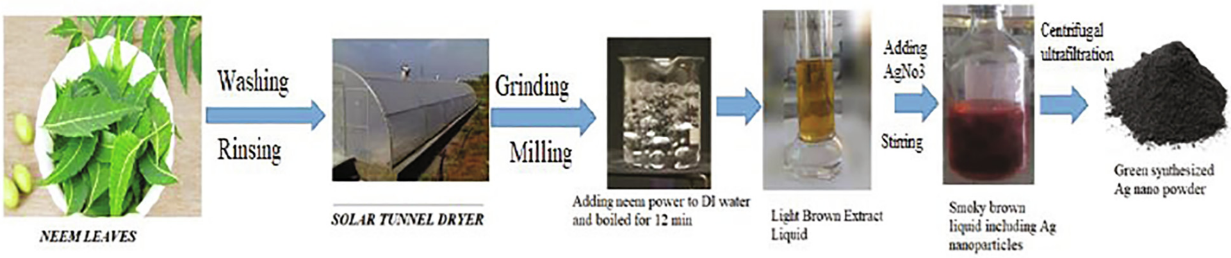

Fig. 1. Green synthesis of silver nano particles. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Fig. 2. Nano fluid preparation.

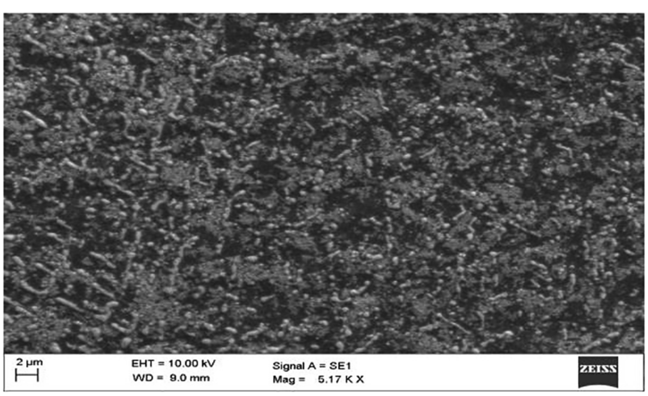

Fig. 3. SEM image of Nano particle.

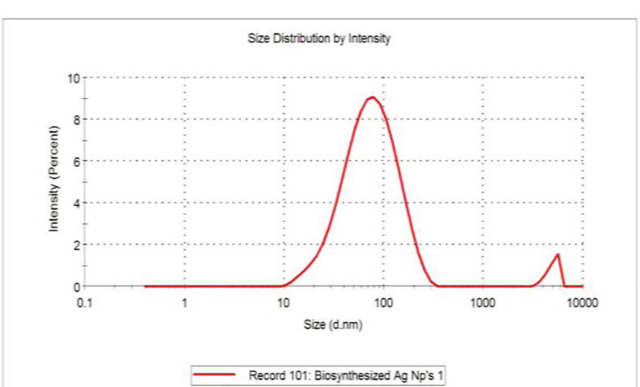

Fig. 4. Size distribution by intensity.

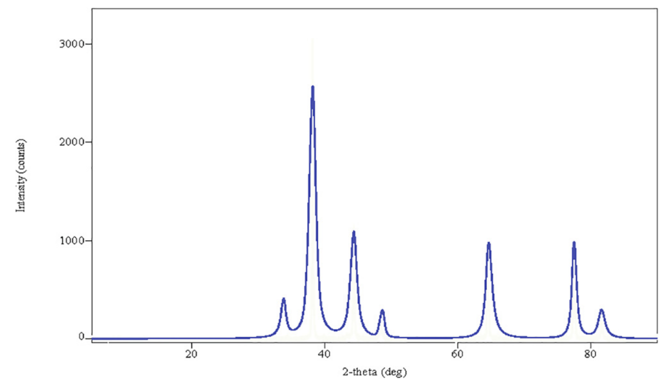

Fig. 5. XRD of green silver nanoparticles. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

at cold fluid inlet. Under laminar flow condition 24 test run results have been noted down for parallel flow.

2. Data reduction

Analysis of heat exchanger is carried out using the following equation

Heat absorbed by cold water $Q_c = m_c \times Cp_c \times (T_{in} - T_{out})$

Heat rejected by hot water $Q_h = m_h \times Cp_h \times (T_{in} - T_{out})$

Area $A = \pi dl$

LMTD $\mathrm{LMTD} = \frac{(\mathrm{Thi}-\mathrm{Tci})-(\mathrm{Tho}-\mathrm{Tco})}{\ln\frac{(\mathrm{Thi}-\mathrm{Tci})}{(\mathrm{Tho}-\mathrm{Tci})}}$

Over all heat transfer coefficient $\mathrm{Q} = \mathrm{U} * \mathrm{A} * \mathrm{LMTD}$

Reynolds number $\mathrm{Re} = \frac{4\mathrm{m}}{\pi * \mathrm{d} * \mu}$

Dean number $\mathrm{De} = \mathrm{Re}\sqrt{\frac{\mathrm{d}}{\mathrm{D}}}$

Nusselt number $\mathrm{Nu} = \frac{\mathrm{h} * \mathrm{d}}{\mathrm{k}}$

Pressure Drop $\Delta\mathrm{p} = \rho * \mathrm{g} * \mathrm{h}$

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

Thermal Performance Factor $\eta = \left(\frac{\left(\frac{\mathrm{Nu_{nf}}}{\mathrm{Nu_w}}\right)}{\left(\frac{\mathrm{f_{nf}}}{\mathrm{f_w}}\right)^{\left(\frac{1}{3}\right)}}\right) * \delta^{0.003}$

3. Result and discussion

The experimental setup is validated with Roger equation for heat transfer study. Experiment was conduct with

DI-water under laminar flow condition i.e. Dean Number is in the range of 500–2000. The experimental results were compared with the theoretical values given by Roger equation it was found that they were in good agreement. Comparison of experimental values with Roger equation is shown in Fig. 8. Experiments were conducted using nanofluid i.e. (agno$_3$ –DI water) for volume con-

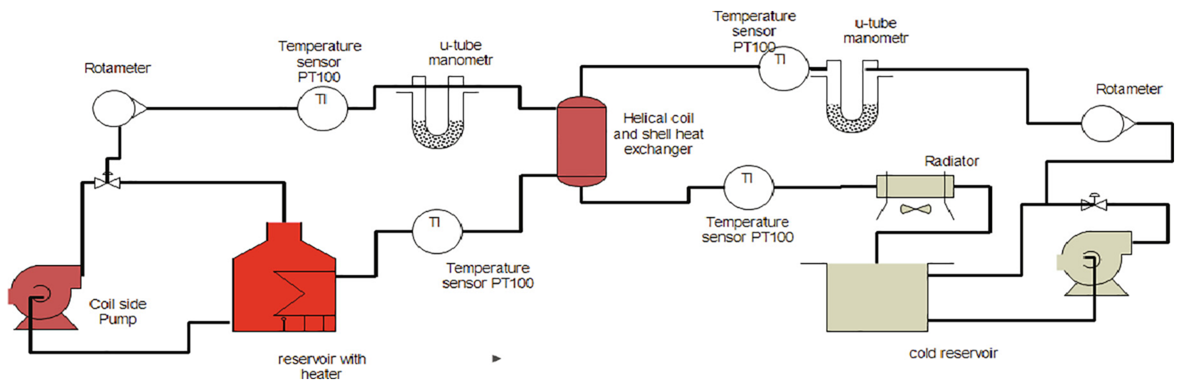

Fig. 6. line diagram of experimental setup .

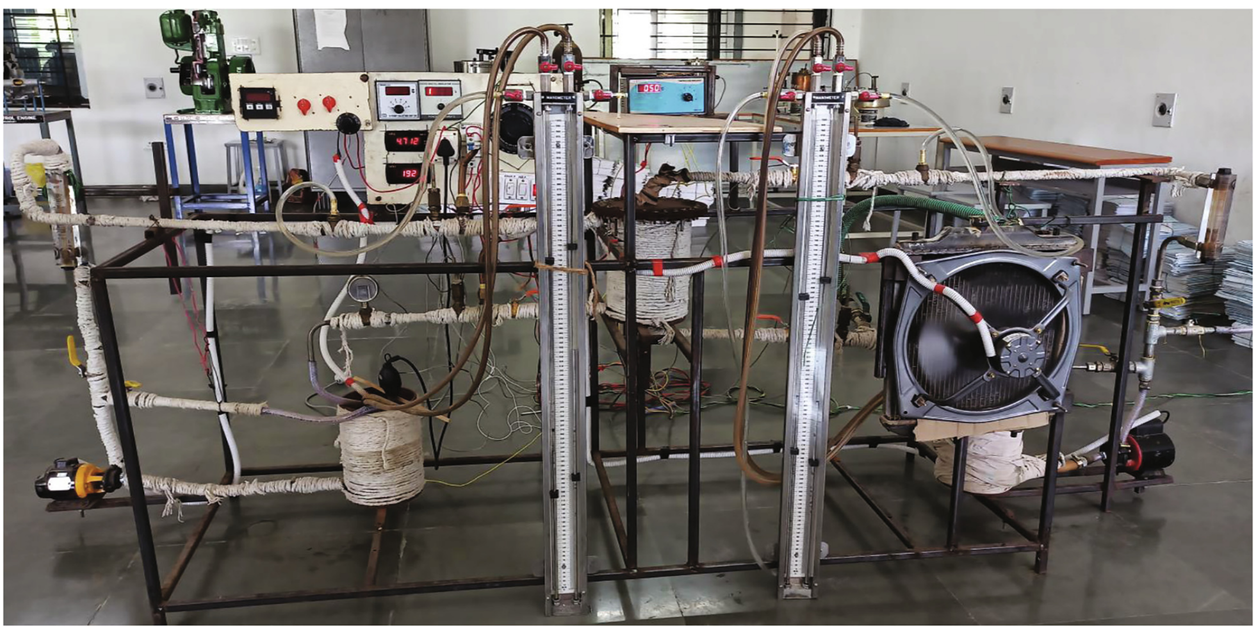

Fig. 7. Experimental setup.

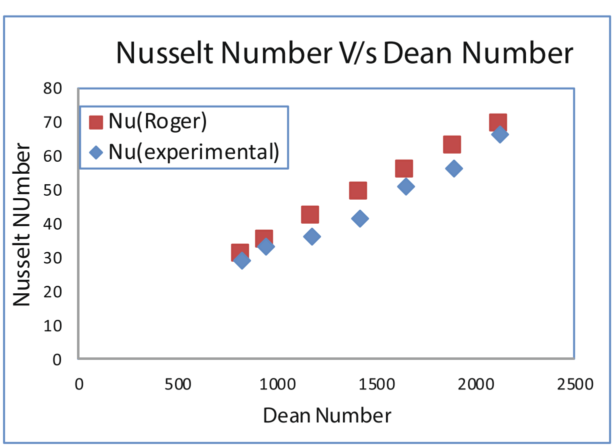

Fig. 8. Nusselt number V/s Dean Number (DI-water).

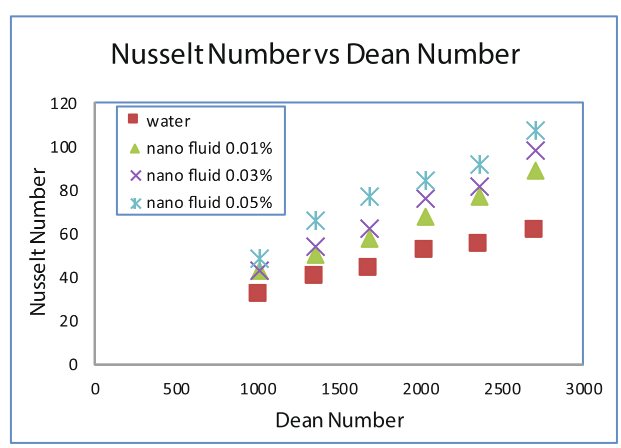

Fig. 9. Nusselt number V/s Dean Number.

centration in the range of 0.01% –0.05%. Tests were conducted for laminar flow with the dean number in the range of 1000–3000. From the graph Fig. 9 it is clear Nusselt number has variation with Dean Number when compared with that of base fluid. From Fig. 10 Convective heat transfer is enhanced with the increase in volume concentration of nano particle and dean number. Heat transfer rate is enhanced due to thermal conductivity of the dispersed nano particle in the base fluid. Various mechanisms have been proposed in

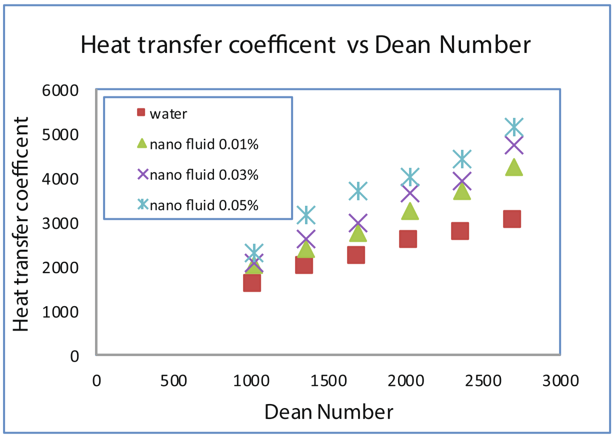

Fig. 10. Heat Transfer Coefficient V/s Dean Number.

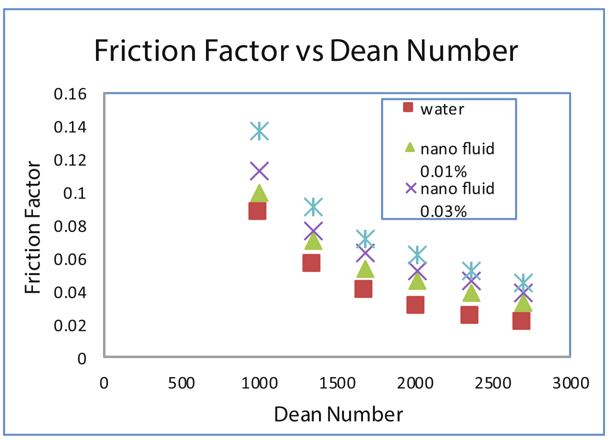

Fig. 11. Friction Factor V/s Dean Number.

justification of enhanced thermal conductivity, among them Brownian mechanism is best suited. Brownian motion is the unpredictable random movement of microscopic particles in a fluid, as a result of uninterrupted bombardment from molecules of the adjoining medium. It is obvious from the test study that the improvement in heat transfers with increment in volume concentration of nano particle and Dean Number. The convective heat transfer enhancement in a tube flow is mainly because of swirl flow. As the swirl prompts the disturbance close to the coil surface and increases the dweller time of nano fluid in the coil. The higher disturbance of the fluid near the coil surface related is answerable for a magnificent fluid blending and effective redevelopment of the thermal and hydrodynamic limit layer which subsequently brings about the improvement of the convective heat transfer by 32%. Augment in Nusselt number compared to DI water is 65% Fig. 11.

3.1. Effect of pressure drop

It is important to enumerate the pressure drop and friction factor in the test section before nanofluids is used in commercial heating and cooling units. During the conduction of experiment pressure drop across the test section is noted down using U-tube manometer to study the flow characteristics of nanofluid. From the experimental value the pressure drop and friction factor in nano fluid has no noteworthy increment comparatively to that of the Di water.

3.2. Thermal performance analysis

In a system for net energy gain, thermal performance factor must be greater than one. For different concentration ratio of nanofluid the variation in thermal performance factor against Dean Number is greater than one under laminar flow condition. Thermal performance factor is used to evaluate the effect of heat transfer rate and pressure in a heat exchanger. From the graph Fig. 12 it indicates that Thermal performance factor slightly decrease with the increase in volume concentration. The above graph show us that concentration of nanofluid used is feasible with respect to energy saving.

4. Conclusion

- An experimental investigation has been carried out to study the heat transfer and Friction Factor characteristics of $AgNo_3$/DI water nanofluid in a helical coil heat exchanger by using varied range of particle volume concentration (0.01%, to 0.05%).
- The use of these nanoparticles has increased the heat transfer rate without significant increase in pressure drop.
- The Nusselt number increases with increase in Reynolds number and nanoparticles concentration. This is due to the thinning of the boundary layer thickness and the influence of nanoparticles Brownian motion and micro-convection of the nanoparticles in the base fluid.
- The Friction Factor has increased as the concentration of nano particle increases.

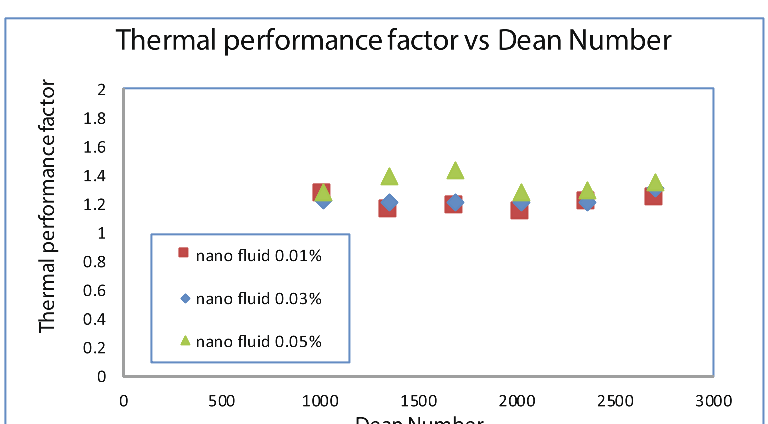

Fig. 12. Thermal performance factor V/s Dean Number.

- The maximum thermal performance factor value of 1.2 was found with the use of $AgNo_3$/DI water nanofluid of 0.05% volume concentration.
- The experimental results show that the thermal performance is better for $AgNo_3$/DI water nano fluid at 0.05% concentration. As the value of Dean Number increases there is a slight decrease in the value of thermal performance factor.

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. **S. Sivaganesan:** 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.

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