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Enhancement of Heat Transfer in Counter Flow Shell and Helical Coil Tube Heat Exchanger (SHCHE) Using Ni-Cu Hybrid Nano Fluid Under Turbulent Flow Regime by Varying Volume Concentration, Pitch, Flow Rate and Coil Material

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Abstract

Experiments under this study were conducted under turbulent flow conditions. The Cu-Ni nanoparticles are prepared using the Sol-Gel method and further surface-treated to reduce sedimentation after suspending these nanoparticles in pure water. The impact of pitch (0.032, 0.042 and 0.052m), mass flow rate, coil material (Aluminium (Al) and Copper (Cu), and volume concentration (0.02, 0.04 and 0.06) on heat transfer rate was computed. Reynolds number (Re), Nusselt number (Nu) were calculated to evaluate the thermal performance of a counter-flow helical coil heat exchanger. It was noticed that the moderate heat transfer rate increased by employing Cu-Ni-distilled water hybrid nanofluid for a 12-turn copper coil with 0.06% volume concentration under turbulent flow conditions compared to distilled water. Further, it was evident that the pressure drop is also compounded by an increase in flow rate and a decrease in the pitch of the helical coil. In turbulent regions, the pressure drop increased by 12.5, 17.64 and 26.3% for 0.02, 0.04 and 0.06 Cu-Ni nano particle volume concentrations, respectively, when related to pure water at Re equal to 14150.

Major Findings: *In the case of a 12-turn copper coil, the overall heat transfer coefficient(U) is improved by 43.71, 52.196 and 60.782 % for 0.02, 0.04 and 0.06 % vol, respectively, compared to distilled water at Re=14150. It is found that the ideal condition to run the shell and helical coil heat exchanger at Re=14150 with 0.06% vol of Cu-Ni hybrid nanofluid.*

Keywords: *Flow Rate, Nano Fluids, Overall Heat Transfer Coefficient, Pressure Drop*

1.0 Introduction

Studies on the enhancement of heat transfer in coil tube heat exchangers have been of interest to many researchers. It is a major criterion in many industries like food processing industries, bioprocess industries, etc., mainly at low temperature working conditions. Parameters such as the geometry, thermo-physical properties of the

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flowing fluid, flow rate, material and pressure drop effect on performance of heat exchangers. Investigations on different ways to improve the rate have been extensively reported. The numerical and experimental methods for evaluating the performance of a heat exchanger for a turbulent flow regime are illustrated. A comparative examination between double pipe and straight tube counter flow heat exchangers for the phenomenon under the same working input parameters is presented[1]. The outcomes of the inner and outer sides of helical pipes were the Number and Nusselt number. It was revealed that the characteristic properties of heat transfer of a double pipe straight tube heat exchanger showed a much better heat transfer coefficient compared to a straight tube heat exchanger. To study the mixed convective heat transfer in a shell and coil tube heat exchanger, experiments were performed by varying coil diameter, Reynolds number, and coil pitch[2]. It was observed that the impact of the diameter of a tube was negligible on the shell side. Further, it was noticed that the coefficient of convective heat transfer was augmented along with an upsurge in coil pitch. The correlation was generated to establish the relation between the Rayleigh number and Nusselt number to find the average diameter of shell side flow. The results specified that the corresponding diameter and length of the shell were the best properties to enhance heat transfer. Experiments were carried out on natural convective heat transfer in a helical coil heat exchanger using water[3]. The outside coil Nu number was correlated with Ra number for dissimilar characteristic lengths. A power law equation was adopted to generate a relationship between Nu and Ra. To study the natural convective heat transfer, the correlations established in the work were applied to find the outlet and inlet temperatures of a coil and the coil dimensions. The coefficients of heat transfer in a newly developed heat exchanger model were evaluated[4]. Different groups of constants were used for unvarying wall temperature and uniform outer wall temperature. An arithmetical elucidation was established for helical flow. The obtained outcomes were validated by neglecting pitch. The impact of the radius of the coil was seemingly represented successfully by the De-number. Experiments were conducted on g-Al_2O_3, CuO and TiO_2 nanofluids to find the convective heat transfer in a horizontal tube for turbulent flow (Re>2300) conditions,[5,6]. In this study, nanoparticles were suspended in Carboxymethyl Cellulose (CMC). A new empirical correlation was suggested to calculate the Nu number for g-Al_2O_3, CuO and TiO_2 /CMC as a function of a Prandtl number (Pr) and a Reynolds (Re) number. The final results revealed that the mean and local coefficient of heat transfer of single-type nanofluids were more than CMO. Apart from this, nanoparticle concentration also plays an important role in the advancement of the heat transfer rate. and CuO /Water of a circular tube heat exchanger was studied[7]. Nanoparticles were prepared and added to an aqueous solution of (k) of single-type nanofluids. Numerical evaluation was carried out by developing a Computational Fluid Dynamics (CFD) model to study the influence on Nusselt (Nu) number and friction (f) factor by varying mass flow rate and nanoparticle volume concentration[8]. For comparison, experimental production procedures, stability evaluation mechanisms, stability enhancement techniques and thermophysical properties of nanofluids were discussed[9]. An ultrasonic device was used for preparing nanofluids. It was observed that ultrasonication increased the temperature of the nanofluid slowly, but it was greatly influenced by the surrounding temperature. The latest advances in preparation methods of hybrid nanofluids and enhancing thermal properties were summarised[10]. Surfactants have been utilised to decrease surface tension in nanofluids and to improve the stability of particles for a long time. It was observed that the excess of surfactant in nanofluids affected the viscosity, thermal conductivity, and stability of hybrid nanofluids. Also noticed that the increase in high Viscosity of nanofluids reduced the thermal efficiency. A recent advance in the dispersion stability of carbon nanoparticles in base fluids was studied[11]. Also, a detailed analysis on specific dispersing examples of both water and oil-based nanofluids with different mechanisms of nanoparticle dispersion and challenges facing while dispersing nanoparticles in base fluids was presented. It was suggested that the ultrasonication process was the best method to improve the stability of carbon nanoparticles in the base fluids. The factors affecting the stability of a silica nanofluid were analysed[12]. In this work, a two-step approach was used to prepare a silica nanofluid. For the dispersion of hydrophobic silica nanoparticles in water, TX-100 surfactant was added in proportion as a dispersant. The PH value distinctly affects the silica nanofluid. It was noticed that silica nanoparticles were not distributed homogeneously under acidic conditions. As per results, the silica nanofluid with a concentration of

0.1 wt. % showed maximum stability. Different heat transfer enhancement techniques were studied on a helical coil heat exchanger to improve the rate of heat transfer[13]. It was observed that by adding nano-additives such as carbon nanofibers, carbon nanotubes and metal nanoparticles, also solid high thermal conductivity inserts like metal foam, metal fins, etc., heat transfer enhancement was attained. The natural convection was considered to achieve a balanced contribution of conduction. From the review, it was learnt that the best enhancement can be obtained via hybrid applications of the heat pipe with fins or metal foams. Enhancement of heat transfer in order to reduce lower overall cost and energy consumption in the shell and tube heat exchanger was investigated[14]. This work objectively aimed to improve the thermo-physical properties, stability, and heat transfer efficiency of a tube in a shell heat exchanger working with CuO/distilled water as the working fluid. It was evident that the use of CuO/pure water increases the efficiency of the heat exchanger and decreases energy consumption as well as overall cost. Heat transfer under turbulent conditions in a shell and helical coil heat exchanger with Fe_2O_3, Al_2O_3 and CuO nanoparticles in aqueous Carboxy Methyl Cellulose (CMC) base fluid was investigated[15]. From the experimentation, the enhancement of heat transfer was attained along with an improvement in nanofluid concentration. The overall coefficient of heat transfer influenced by the twisted tape on heat transfer was much more significant compared to nanoparticles in the base fluid. The Nusselt number and thermal change in wing depth ratio (w/w) decreased with the performance factor, whole diameter ratio (d/w). The different ways to reduce fouling and pressure drop with and without helical baffles in Shell and Tube Heat Exchangers (STHXs) were evaluated[16]. The results showed that low fouling tendency and better heat transfer were attained with baffles. The Helical baffles provide smooth behaviour of the fluid flow in the shell side, which leads to lower pressure drop. At the end, helical baffles indicate higher heat transfer for the same pressure drop. The impact of geometrical parameters, non-dimensional numbers on the efficiency of helical coil on heat transfer was studied[17]. It revealed that the Nusselt number was increased with a non-monotonic change in the friction factor inside the coil. Further investigations were carried out on wire coils with varying pitch, which showed a better heat transfer phenomenon. It was evident that a lower pitch would result in a better heat transfer rate. Overall heat transfer by varying pitch in a double pipe helical heat exchanger under turbulent conditions was analysed[18]. It was observed that the numerical analysis showed that the parametric change in turns number where there was a change in the dean number of the geometry, which affected the overall heat transfer coefficient. It was also observed that the heat transfer rate improved with a decrease in coil pitch. To study the heat transfer performance characteristic properties of a helical double-tube heat exchanger, experiments were conducted with CuO and TiO_2 nanofluids by varying volume concentrations under laminar flow conditions[19]. Experiments were conducted by varying the mass flow rate of the water from the annulus, and the mass flow rate of the nanofluid inside the tube was kept constant. The impact on the heat transfer rates and heat transfer coefficients was determined by changing of Dean number and volume concentration of nanoparticles. It was observed that the dispersed CuO and TiO_2 nanoparticles in water under a laminar flow regime showed a significant enhancement in heat transfer. The numerical study was validated by comparing it with the empirical equations. A comparative study for thermal performance in straight circular duct using Al_2O_3- pure water and CuO-pure water nanofluids with helical screw tape inserts under constant heat flux condition was presented[20]. The better heat transfer was obtained in CuO- pure water compared to Al_2O_3-pure water with helical screw tape inserts. The friction factor was increased considerably in both nanofluids with helical screw tape inserts along with heat transfer rate. At all Peclet numbers, the thermal performance factor for all twist ratios was higher for both Al_2O_3-pure water and CuO-pure water nanofluids compared to pure water. This indicates in laminar flow regime straight circular duct that helical screw tape inserts with different twist ratios was suitable in terms of energy saving. The impact of cross-section lobe number (n=2, 3, 4, 5, and 6), coil pitch, coil height and pressure drop on heat transfer under laminar flow conditions was studied numerically[21]. Computational fluid dynamics codes were employed for the simulation of an HC with distinct cross-sectional areas. To produce a fine mesh near the coil wall for developing high velocity and temperature gradient, a non-uniform mesh was adopted. The highest Nusselt number was found at the helical coil with several turns equal to 6, and the friction factor among all other lobed cross sections was less. It was determined that the Nusselt

number (Nu) and coefficient of friction factor (fe) were enhanced with reduced coil diameter. A 3-dimensional periodic cross flow in the pipe with a continuous heat flux and different wall boundary conditions in a helical coil heat exchanger with novel Anchor-Vortex Generators (AVG) was computed[22]. The rate of fluid flow and heat transfer characteristic properties were analysed for 3000 <Re> 18,000. It was noticed that AVG insets affect the stream organisation and thermal fields. Also, the AVG inserts produce the recirculation vortex flow in the coil and promote a maximum turbulent force close to the wall and centre core areas. Vortex flow introduces a thin boundary layer that enhances the rate of heat transfer. It was concluded that nanofluids enhanced the heat transfer rate. The characteristic properties of a concentric tube heat exchanger under Re<5000, heat transfer(U) and pressure drop(p) of Aluminium oxide-water single nanofluid with inserts and without inserts tabulator's were computed[23]. It was observed that the pressure drop and Reynolds number in the case of water were almost equal to the values attained using Al_2O_3-water nanofluid. It was evident that the 'U' was enhanced by inserting wire coils in the shell, and was more suitable for heat transfer improvement drives. To study the impact of different coil diameters, mass flow rates and coil pitch on heat transfer rate in shell and coiled tube heat exchangers, experiments were performed[24] The Wilson plots were used for finding heat transfer coefficients on both the straight tube and shell side. The mixed flow heat transfer rate was studied in counter flow heat exchanger[25]. It was evident that the heat transfer rate was enhanced with higher coil diameter, coil pitch. But the heat transfer rate was decreased along with an increase in mass flow rate in the shell and tube. The characteristic properties of heat transfer and pressure drop of using Al_2O_3-pure water single-type nanofluid in helical coil tube heat exchanger for steady state laminar fluid flow were analysed[26]. The increase in the heat transfer rate was observed with an increase in nanoparticle volume concentration and using a helical coil tube. With an increase in Re value, the heat transfer coefficient also improved. To evaluate pressure drop and overall heat transfer in helical coil heat exchanger experiments were conducted with alumina–silver nano composite at 0.1 to 0.4% volume concentrations[27]. At stable wall temperature, all experimental outcomes were examined. It was observed that the heat transfer rate was augmented by 31.585% when related to D2 at a concentration of 0.4% alumina–silver nanoparticles. The impact of nanofluid on the rate of heat transfer and pressure drop in the turbulent flow regime in a concentric tube heat exchanger was examined[28]. The SiO_2-water with a particle average diameter of 30nm was employed as a flowing fluid. Experiments were conducted by varying the heights and pitches of the tube. Results were evident that heat transfer increased appreciably with the addition of nanoparticles and varying constructional parameters, with a small pressure drop. In the circular pipe heat exchanger role of relative Nusselt number on the enhancement of heat transfer was also evaluated. The influence of constructional parameters and flow rate on the coefficient of heat transfer in a vertical helical coil heat exchanger was computed[29]. The tests were conducted for both laminar and turbulent flow conditions on the coil side. A considerable influence on the axial temperature of the helical coil tube heat exchanger was noticed at different mass flow rates. It was also observed that the ε–Nephelometric Turbidity Unit (NTU) correlation of mixed convection heat transfer and a counter-flow heat exchanger was the same. Further, the Logarithmic Mean Temperature Difference (LMTD) was reduced with an increase in mass flow rate. Thermal performance of a helical coil heat exchanger for various Reynolds and constructional parameters was investigated[30]. The objective of this work was to evaluate the influence of change in coil diameter, mass flow rate, and pitch on the heat transfer rate of a vertical shell and helical coiled tube heat exchanger. On the coil side, the various tests were performed under the regime of laminar as well as turbulent flow. It was observed that the ε–NTU relation of the counter-flow heat exchanger and the mixed convection heat exchanger was the same.

2.0 Experimentation

The overall heat transfer in heat exchangers is influenced by numerous parameters. The most important parameters are the geometrical parameters of the coil, fluid temperature, flowing fluids, type of flow, volume concentration, thermal conductivity of heat carriers, pressure drop, etc. Hence, there is a need to consider various variables to build a test facility. The present chapter illustrates the experimental setup and preparation of nanofluids for experimental investigations on counter-flow vertical shell and helical coil heat exchangers. transfer in heat exchangers is

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2.1 Experimental Test Facility

The shell and helical coil heat exchanger is designed and fabricated to investigate the heat transfer characteristic properties to enhance the heat transfer rate. It consists of the following features.

- Shell and coil arrangement system
- Flow measurement and control system
- Pressure measurement system
- Instrumentation system

The combined form of all the above subsystem experimental test systems is shown in Figure 1.

2.2 Methodology

2.2.1 Modeling Section

The Cu-Ni-distilled water hybrid nanofluid density[27] is determined by applying formula (1).

$$\rho nf = \varphi\ \rho np + (1-\varphi)\ \rho bf \quad (1)$$

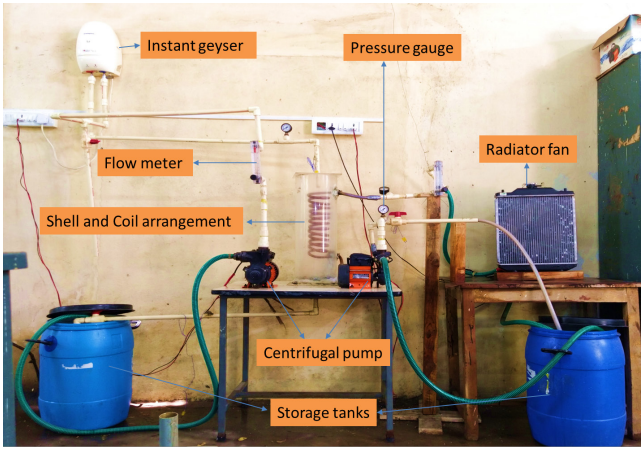


Figure 1. Photographic view of experimental test set-up in the laboratory.

The specific heat of Cu- Cu-Cu-Ni-distilled water hybrid nanofluid[27] is computed by adopting Equation (2).

$$(\rho\ Cp)nf = \varphi\ (\rho\ Cp)np + (1-\varphi)\ (\rho\ Cp)bf \quad (2)$$

2.2.2 Experimental data evaluation

The copper coil's external surface is perfectly shielded to prevent heat from escaping when it is in contact with the surrounding atmosphere. Therefore, the heat gained by the Cu-Ni-distilled water hybrid nanofluid is equal to the heat rejected by the hot water[27].

$$Qnf = CPnf\ mnf.(Tout,nf - Tin,nf) \quad (3)$$

$$Qw = CPw\ mw(Tout,w - Tin,w) \quad (4)$$

The average and coefficient of overall heat transfer of Cu-Ni-Distilled water and distilled water[27] are obtained by following Equations (5) and (6).

$$Qavg = \frac{Qw + Q}{2} \quad (5)$$

$$Qove = UAi\Delta Tlm \quad (6)$$

The copper coil internal surface area is determined[28] by adopting Equation (7). Temperature variations for different heat inputs on the shell side (hot fluid) and coil side (cold fluid) are evaluated by using equations (8(i)) and (8(ii)). The LMTD is estimated by applying Equation (9)

$$Ai = \Pi DiL \quad (7)$$

$$\Delta T1 = \Delta Th,i - \Delta Tc,o \quad 8\ (i)$$

$$\Delta T2 = \Delta Th,o - \Delta Tc,i \quad (8)\ (ii)$$

$$\Delta Tlm = \frac{\Delta T2 - \Delta T1}{\Delta T2 / \Delta T1} \quad (9)$$

By applying Equations (10) and (11), the heat transfer coefficient (h) and friction factor (f) of a flowing fluid in a helical coil are calculated[18].

$$h(exp) = \frac{m.cp.(Th1 - Th2)}{(Tw - Th)M} \quad (10)$$

$$f = 0.316\ Re^{-0.25} \quad (11)$$

To explain the behaviour of the fluid flow, Reynolds (Re) and Prandtl (Pr) numbers are considered as crucial parameters. These parameters are assessed by employing Equations (12) and (13) on the coil side[28] (concerning the heat transfer data book).

$$Re(nano) = \rho.U.d/\mu \quad (12)$$

$$Pr(nano) = Cp\ .\ \mu/k \quad (13)$$

Nusselt number (Nu) of hybrid nanofluid, if calculated by varying Reynolds and Prandtl numbers in helical coil, is calculated by using Equation (14) to find the best possible Nusselt number attaining maximum heat transfer[27].

$$Nuc = 0.13.\ (f.\ Re^2\ .\ Pr)^{1/3} \quad (14)$$

3. Results and Discussion

The graph for variation in Nusselt number for 8-turn Copper and aluminium coils with respect to Reynolds number for different heat inputs is shown in Figure 2. The Cu-Ni nanoparticles are added in (0.02, 0.04 and 0.06% Vol) different volume concentrations to the base fluid for experimental analysis. It is seen that the Nusselt number is improved at all concentrations compared to distilled water. Among all Cu-Ni nanoparticle concentrations, Cu-Ni-Distilled hybrid nanofluid with 0.06% Vol shows the maximum rise in Nusselt number along with an increase in Reynolds number from 2986 to 14150. This is due to an improvement in flow rate and an enhancement in nanoparticle concentration. When flow is turbulent, proper mixing of particles takes place inside the coil. Nusselt number under turbulent flow regime of 8 8-turn aluminium coil compared to laminar flow is increased by 11.31, 17.75 and 16.16%. The maximum Nusselt number is noticed at 0.04% Vol under the same test conditions. And these variations, compared to the copper helical coil, are decreased by 13.62, 1.75 and 7.16% under the same test conditions. The graph shown in Figure 3 illustrates the variation in Nu number along with Re number for 10 10-turn aluminium coil. From the graph, it is noticed that the Nusselt number is minimum for Reynolds numbers that vary between 2846 to 5823.This is because of a decrease in pitch and an increase in contact area. The pitch of the coil decreases the contact time between the cold and hot fluid, increases further, heat exchange between the hot and cold fluid increases. Due to this Nusselt number increases. In all the cases, the length and coil diameter are constant. The Nusselt number of Cu-Ni-Distilled hybrid nanofluid with 0.02, 0.04 and 0.06% Vol is increased by 30.69, 33.17, 37.90 % respectively, when compared to pure water at a Reynolds number equal to 14150.The Nusselt number in the case of 10 10-turn copper coil, compared to distilled water, increased by 30.68,37.22 and 41.88% for 0.02, 0.04 and 0.06 % Vol, under the same test conditions for the same mass flow rates varying from 0.000008 Kg/s to 0.000018kg/s. The maximum percentage variation in Nusselt number

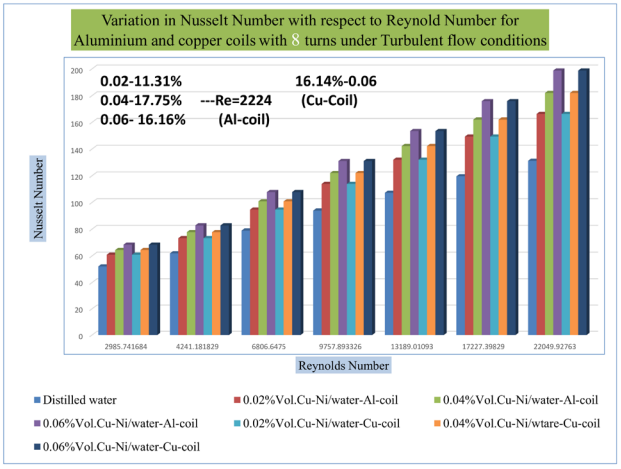


Figure 2. Variation in Nusselt number with respect to Reynolds number for Aluminium and copper coils with 8 turns under turbulent flow conditions.

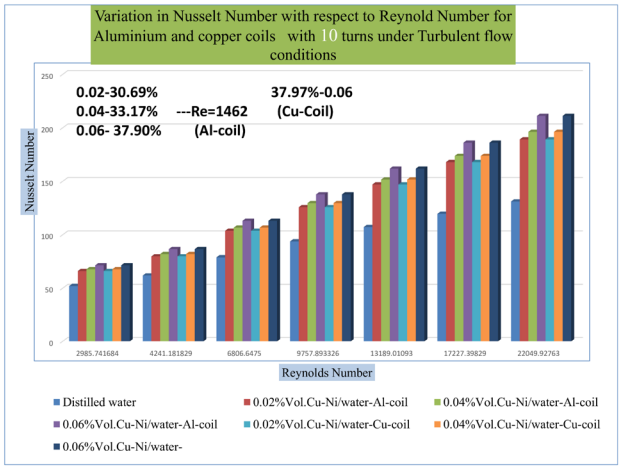


Figure 3. Variation in Nusselt number with respect to Reynolds number for Aluminium and copper coils with 10 turns under turbulent flow conditions.

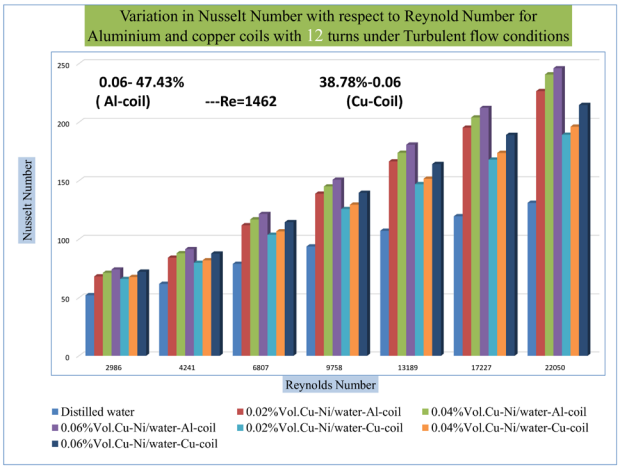


Figure 4. Variation in Nusselt number with respect to Reynolds number for Aluminium and copper coils with 12 turns under turbulent flow conditions.

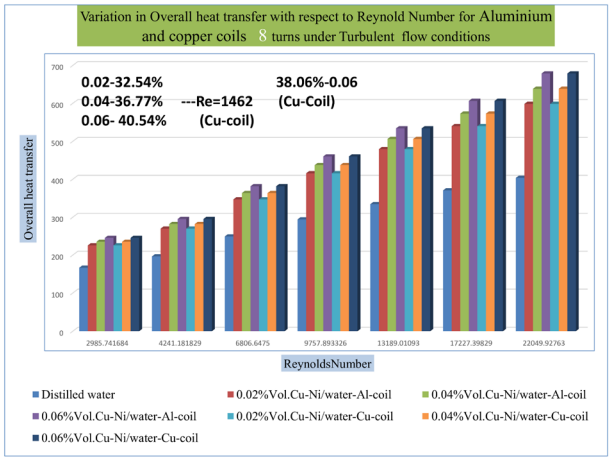


Figure 5. Variation in overall heat transfer with respect to Reynolds number for Aluminium and copper coils, 8 turns under turbulent flow conditions.

attained is 18.23% more with 0.06%Vol when compared to 8 8-turn copper coil at a Reynolds number equal to 2224.The Nu versus Re number for a 12-turn aluminium coil is indicated in Figure 4. The increased Nusselt number is observed along with an upsurge in Reynolds number. This is due to an increase in nanoparticle concentration and a decrease in pith. The time of fluid flow inside the aluminium coil increases with a reduction in pitch of the coil. Further, heat exchange between the hot fluid and Cu-Ni-Distilled hybrid nanofluid increases. Due to this Nusselt number increases in counterflow vertical Shell and Helical Coil Tube Heat Exchanger (SHCHE). The Nusselt number increases by 42.12, 46.70 and 47.13 % for 0.02, 0.04 and 0.06 % Vol, respectively, when compared to distilled water. It is also evident that the Nusselt number under turbulent flow conditions, compared to laminar flow regime under the same test conditions, is increased by 18.11, 19.37 and 14.83 %. Among 8, 10 and 12-turn copper coils under laminar flow conditions, the 12-turn copper coil with 0.06% Vol shows the maximum Nu number with the mass flow rate of 0.000018kg/s. The variation in overall heat transfer coefficient (U) with respect to Reynolds number (Re) of 8-turn aluminium and copper coils is shown in Figure 5. The enhanced (h) heat transfer coefficient is noticed with an upsurge in (Re) from 2986 to 14150. This is due to the radius of curvature of an Al and Cu coil and the mass flow rate. The curvature radius of the coil develops centrifugal force in the helical coil. The increase in mass flow rate of Cu Ni nano particles is distributed evenly in the base fluid. Due to these reasons, the heat exchange between hot water and Cu-Ni-Distilled hybrid nanofluid improves. The overall heat transfer coefficient is increased by 32.54,36.77, and 40.54 % for 0.02,0.04 and 0.06 %Vol, respectively, compared to distilled water at a Reynolds number equal to 14150. Under turbulent flow regime, it is studied that the overall heat transfer coefficient compared to laminar flow for the same test conditions is increased by 1.73, 4.35 and 3.99 % for 0.02, 0.04 and 0.06, respectively, at a Reynolds number equal to 14150. Figure 6 illustrates the change in 'U' with Re number for 10-turn copper and aluminium (Al) helical coils under turbulent flow conditions. It is noticed that the coefficient of 'U' is improved with an increase in particle volume concentration and a decrease in pitch. Due to an increase in volume concentration of Cu-Ni nanoparticles in distilled water and an increase in the number of turns, contact time between hot fluid and Cu-Ni-distilled water hybrid nanofluid increases. Further heat gain by the Cu-Ni-Distilled water increases. The extreme heat transfer coefficient (h) reached with 0.06% Vol Cu-Ni-Distilled water hybrid nanofluid is 707.503 W/m^2-K when the Reynolds number equals 14150.The overall heat transfer coefficient using Cu-Ni-Distilled hybrid nanofluids compared to distilled water increased by 32.54, 36.77, and 40.54 % with 0.02, 0.04 and 0.06 volume concentrations, respectively. 'U' under turbulent flow conditions compared with laminar flow is increased by 2.16, 3.0, and 4.601 % for the same test conditions. The graph of the overall heat transfer coefficient variation

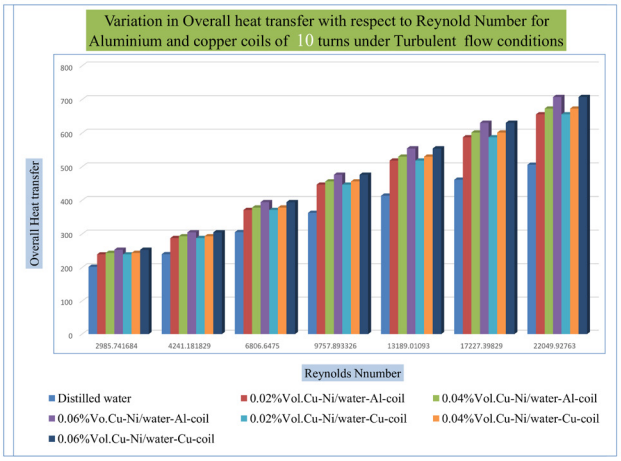


Figure 6. Variation in overall heat transfer with respect to Reynolds number for Aluminium and copper coils, 10 turns under turbulent flow conditions.

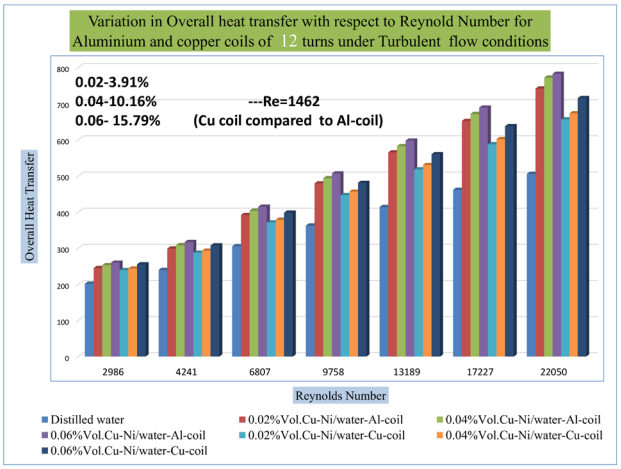


Figure 7. Variation in overall heat transfer with respect to Reynolds number for Aluminium and copper coils, 12 turns under turbulent flow conditions

with respect to Reynolds number for 12 12-turn aluminium coil is shown in Figure 7. The increased overall heat transfer coefficient is seen with a reduction in pitch and an increase in volume concentration of Cu-Ni nano particles. This is due to the direction of flow inside the coil and the mass flow rate. Because of counterflow flow the time of contact between nanoparticles and hot water increases, further heat gained by the cold fluid also increases. Among all Cu-Ni nanoparticle concentrations (0.02, 0.04, and 0.06) base fluid with 0.06% Vol shows the maximum overall heat transfer coefficient when compared to distilled water, i.e 36.14% at a Reynolds number equal to 14150. The variation in overall heat transfer coefficient

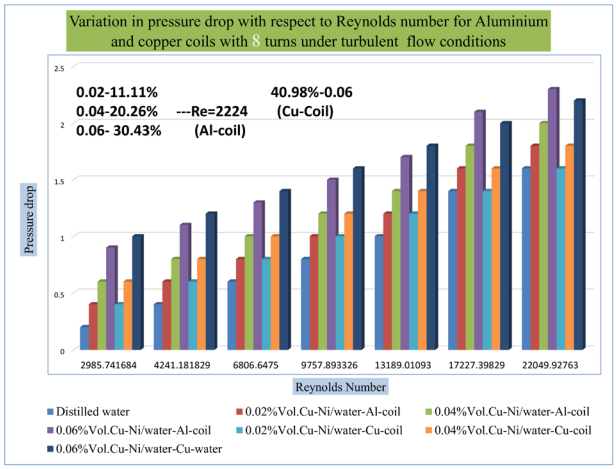


Figure 8. Variation in pressure drop with respect to Reynolds number for Aluminium and copper coils with 8 turns under turbulent flow conditions.

in turbulent flow regime is increased by 3.91, 10.61, and 15.79 % compared to laminar flow under the same test conditions. Deviation in pressure drop along with an increase in Reynolds number for 8 8-turn aluminium coil is demonstrated in Figure 8. The improved pressure drop is noticed with a rise in Reynolds number under the turbulent flow regime. This is due to the counterflow of Cu-Ni-water hybrid nanofluid inside the coil and the density of nanoparticles in distilled water. Because of the density of nanoparticles, it opposes the flow of fluid in the counterflow direction inside the coil. From the graph, it is noticed that the pressure drop sharply varies from 2486 to 3843 and between 3844 to 9902 pressure drop varies uniformly. After this, the pressure drop changes steeply from 9903 to 14105. When compared to the base fluid, the pressure drop using Cu-Ni-Distilled hybrid nanofluid with 0.02, 0.04 and 0.06 %Vol increased by 11.11, 20.6 and 30.43 % correspondingly. Among all nanoparticle concentrations, the maximum pressure drop is attained at Re=14510 with a concentration of 0.06% under turbulent flow regime, and when it is compared to laminar flow conditions with the same test conditions is increased by 11.30%. It is suitable to operate the shell and helical coil heat exchanger within the range of Re=3843 to 9902 for consistent output. Figure 9 shows the pressure drop versus Reynolds number in 10-turn Cu and Al coils with Cu-Ni-Hybrid nanofluid of 0.02, 0.04 and 0.06 %Vol for Reynolds number ranges from 2986 to 14150. Within this range, the pressure drop is enhanced with an increase in flow rate. The flow modification is owing to centrifugal force in

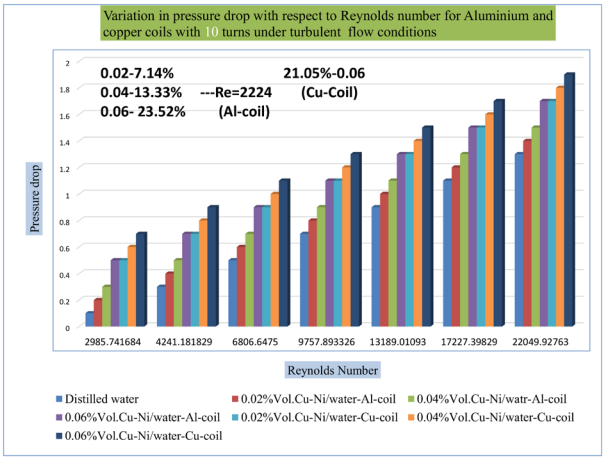


Figure 9. Variation in pressure drop with respect to Reynolds number for Aluminium and copper coils with 10 turns under turbulent flow conditions.

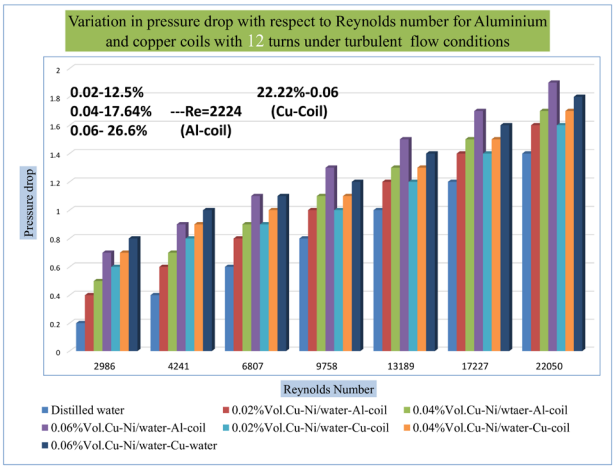


Figure 10. Variation in pressure drop with respect to Reynolds number for Aluminium and copper coils with 12 turns under turbulent flow conditions.

the aluminium coil tube. The centrifugal force develops secondary flow, which enriches the heat transfer rate, but the pressure drop also increases. Among 0.02, 0.04, and 0.06 % Vol Cu-Ni-Distilled hybrid nanofluids, 0.06% Vol shows the maximum pressure drop at Re=14150. Pressure drop in case of turbulent flow is increased by 7.14, 13.33 and 23.52 % for 0.02, 0.04 and 0.06 % Vol respectively of Cu -Cu-Ni-Distilled water hybrid nanofluids when compared to distilled water. This percentage variation compared to laminar flow conditions for 0.06 volume concentration is higher by 1.19% for the same input parameters. The variation in pressure drop in 12 12-turn aluminium coil with respect to Reynolds number under turbulent flow conditions is shown in Figure 10. It is examined that ΔP is developed with a reduction in pitch and an increase in Re number. The decrease in pitch of the coil number of turns rises, and more curvature increases. Due to an increase in curvature area, secondary flow develops inside the coil, further the pressure drop rises from the inlet to the outlet of the aluminium helical coil. The sedimentation of the Cu- Ni nanoparticles in the base fluid is also noticed, and it is one of the causes for the pressure drop. The pressure drop in the transition region (Re=2846 to 3843) increased by 50% for all volume concentrations, including distilled water. In a turbulent region, the pressure drop increased by 12.5, 17.64 and 26.3 % for 0.02, 0.04 and 0.06 Cu-Ni nano particle volume concentrations, respectively. When related to pure water, Re equals 14150. This ΔP variation in under laminar flow conditions compared to turbulent flow conditions is 0, 20.96 and 12.33 % more for the same Cu-Ni nano particle concentrations and flow rate.

4.0 Conclusion

- Nusselt number under turbulent flow regime of 8-turn aluminium coil compared to laminar flow is increased by 11.31, 17.75 and 16.16 %. The maximum Nusselt number is noticed at 0.04% Vol under the same test conditions. This is because of an increase in flow rate and volume concentration.
- Nusselt number under turbulent flow regime of 8-turn aluminium coil compared to laminar flow is increased by 11.31, 17.75 and 16.16 %. The maximum Nusselt number is noticed at 0.04 % Vol under the same test conditions. This is because of an increase in flow rate and volume concentration.
- Nusselt number under turbulent flow regime of 10-turn aluminium coil compared to laminar flow is increased by 0.46, 1.46, and 0.59 %. This is because of the uniform distribution of Cu-Ni nanoparticles in the base fluid and mass flow rate. The maximum per cent variation in Nusselt number is attained at 0.04 %Vol under laminar flow.
- The variation in Nusselt number in a 10-turn copper coil under turbulent flow compared to an aluminium coil is increased by 13.9, 16.34, and 14.845 %. The maximum Nusselt number was noticed at 0.06 %Vol under the same test conditions at a Reynolds number equal to 14150. This is because of a change in coil material and flow rate.

- The Nusselt number in the case of 12 12-turn helical copper coil tube is increased by 48.919, 54.66 and 74.53% for 0.02, 0.04, and 0.06 %Vol, respectively, compared to distilled water at Re=14150. It is because of a rise in flow rate and volume concentration of Cu-Ni nano particles.
- The Nusselt number of 12 12-turn copper helical coil under turbulent flow increased by 8.23, 9.49 and 6.31 % compared to a 12-turn aluminium helical coil at a Reynolds number equal to 14150. The maximum Nusselt number is attained with 0.06 %Vol for different heat inputs. It is because of the good 'k' of coil material(Cu) and volume concentration.
- Overall heat transfer coefficient under turbulent flow regime of 8-turn copper coil compared to 8-turn aluminium coil is increased by 1, 2.18 and 1.13 %. The highest per cent variation in Nusselt number is noticed at 0.04 %Vol under the same test conditions. And the maximum overall heat transfer attained at Re=14150 with 0.06% volume concentration of Cu-Ni-Distilled water hybrid nanofluid.
- Under the turbulent flow regime, the 'U' of the 10-turn Cu coil compared to the Al coil is increased by 2.88, 10.44 and 13.55 %. The maximum Nusselt number is obtained copper coil with 0.06 %Vol at a Reynolds number equal to 14150. This is because of the thermal and physical properties of coil materials.
- The overall heat transfer coefficient in a 12-turn copper coil compared with a 12-turn aluminium coil under turbulent flow for the same temperature inputs, the copper coil shows 3.91,10.16 and 15.79 % rise in overall heat transfer at a Reynolds number equal to 14150 with 0.06% Vol Cu-Ni nanoparticles. This is due to the flow rate and coil material.
- From all observations, it is evident that a 12-turn copper coil with 0.06 volume concentration Cu-Ni-Distilled water hybrid nanofluid under turbulent flow conditions shows the highest overall heat transfer with less pressure drop in counter flow vertical shell and helical coil heat exchange.

5.0 Future Scope

- Further experiments can be conducted on different geometries, such as square, double spherical, etc., to improve the heat transfer rate in vertical shell and helical coil heat exchangers.
- The present investigations are carried out at different volume concentrations of nanofluids, coil material, and pitch for fixed length and diameter. The future experiments can be proposed considering coil length and diameter as variables while keeping pitch constant.
- Numerical approaches can be used to determine complex three-dimensional flow patterns around a helical coil
- The future experiments can also be proposed considering inserts and boundary conditions
- Influence of surface roughness and vibrations on helical coil for different inclinations can be considered for future work.
- The impact of Prandtl number on free and forced convection for the coil can be considered for further investigations.

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