HEAT TRANSFER ENHANCEMENT IN A HELICALLY COILED CONVERGENT AND DIVERGENT TUBE HEAT EXCHANGER WITH Al_2O_3 NANOFLUID

by

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Original scientific paper
https://doi.org/10.2298/TSCI221205140S

In this investigation, the analysis of the heat transfer coefficient of a shell, helically coiled convergent-divergent tube heat exchanger has been carried out by utilizing Al_2O_3-water nanofluid. The nanofluid was prepared using a two-stage technique with proportions of 0.1 vol.%, 0.3 vol.%, and 0.5 vol.%. The inner heat transfer coefficient, overall heat transfer coefficient, and Nusselt number were analyzed and it found that the heat transfer coefficient is increased, with increase of inner dean number and particle volume concentration. The experimental tests were carried out in the range of Dean number, 1100 < De < 4200. When compared to base fluid, the overall heat transfer coefficient improved by 27%, 55%, and 78% at 0.1%, 0.3% and 0.5% with Al_2O_3-water nanofluid, respectively. When compared to base fluid at a fixed dean number, the increase in Nusselt number was viewed as 27%, 51%, and 72% at 0.1%, 0.3%, and 0.5% of Al_2O_3-water nanofluid, respectively. The investigations of enhancement were increased due to increased nanofluid thermal conductivity while increasing the vol.% concentration and Brownian movement of the nanoparticles. The viscosity of nanofluid is increased with increase of particle volume which increase the pressure drop. It is concluded the convergent-divergent helically coiled tube heat exchangers along with nanofluid is able to enhance the heat transfer with considerable pressure drop. There is no adverse effect on the development of optional streams or the blending of liquids.

Key words: *convergent-divergent helically coiled tube, nanofluid, Al_2O_3, heat transfer coefficient*

Introduction

Many industries depend heavily on heat transfer including chemical processing, electric power generation, power grid stations, electronic component cooling, air conditioning systems, ventilation, and engine cooling. New technologies have high energy costs and materials to centralize the life of the equipment, increasing the drive to produce more effective heat exchange and energy efficiency. The heat transfer approaches have three different augmentation methods. Those methods are passive, active, and a combination of both passive and active. When using heat transfer in active mode, some external power is needed to make the flow adjustments for the heat transfer improvement in terms of injection, surface vibration,

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mechanical aids, fluid vibration, and electrostatic field. The methods which do not need any external power are passive heat transfer such as a coiled tube, surface tension, swirl flow device, rough surface, treated surface, and additives for liquid. The combination of passive and active heat transfer approaches is called the compound heat transfer approach, which is simultaneously utilized in most fluid-flow heat transfer. In convection mode, the flow fluids like ethylene glycol, engine oil, and water naturally do not have better heat transfer coefficients. Further, these fluids have some boundaries in terms of cooling capacity. Micro, macro, and nanoparticles are floated in flowing fluids and were considered as resolving agents for heat transfer problems in the ability of conventional heat transfer fluids. The suspension of metallic nanoparticles in conventional heat transfer fluids such as water resulted in a significant reduction in heat exchanger pumping power in industrial applications, which also improved heat transfer [1]. The research was conducted on a conical coil heat exchanger without any nanofluid combination. The exploration set-up includes fifteen coils of cone angles of 135°, 90°, 45°, and 0° (vertical helical), and 180° (horizontal spiral) that were manufactured as well as analyzed with similar tube lengths, coil diameter, and three tube diameters. The Nusselt number is increased with helical coils and decreased with spherical coils [2]. The pressure drops and heat transfer coefficient increased when using different wire coils inserted in straight tubes, and using nanofluid it further increased [3]. The heat transmission and pressure decrease in helically coiled tube heat transfer working fluid as Al_2O_3 nanofluids in a turbulent flow area. The rise in heat transfer coefficients and pressure decrease is accelerated as particle concentration increases. The helically coiled tubes were tested by using Al_2O_3 nanofluid under laminar flow. It was found that higher particle volume concentration increased the friction factor of the flow by the addition of particles with 0.1 vol.%, 0.4 vol.%, and 0.8 vol.% to the base fluid, also increasing the viscosity of the nanofluid. Furthermore, the secondary flow formations are created by the helical coil in the coil tube, with no impact on the performance of the heat exchanger [4]. The pressure drops and heat transfer analysis of the cone helically coil tube heat exchanger using MWCNT nanofluid and nanofluid preparation were done by using two-step methods by adding SDBS surfactant. From the result, it was concluded that the max 45% in overall HTC, 52% in inner HTC, and 56% in inner Nusselt number is higher than water at a concentration of 0.5% volume [5]. In a double helically coiled tube heat exchanger using MWCNT nanofluid, a 35% convective heat transfer was recorded at 0.6% volume concentration, with a 40% friction factor drawn when compared to water [6]. Moreover, the optimal and crucial values of dimensionless parameters like *p/dt, Hc/f, Hsh/dsh, dc/dt*, and *dv/f* were analyzed. The coefficient of design is used to maximize the heat transfer rate and the minimized entropy generation rate has also been found [7]. The present work is on a helically coiled heat exchanger with CuO-water nanofluid with a 0 vol.% to 0.5 vol.% concentration. The flow rate and particle loading on Nusselt number and heat transfer coefficient (HTC) are established with this exploration. The HTC for Re = 812 is 99.9 W/m^2 °C, and the HTC for Re = 1895 is 544.46 W/m^2 °C [8]. The pressure drop and HTC are directly proportional to the curvature ratio and Reynolds number. Also, using CuO as a nanofluid, 16-17% HTC increases and 14-16% pressure drop increases were noted compared to water [9]. The heat transfer was increased with different nanofluids with different concentrations, and it was discovered that the selection of nanoparticles is more important than fluid temperature and volume flow rate [10]. The maximum enhancement in Nusselt number was 44.64% in SiO_2 nanofluid and 41.82% in Al_2O_3 nanofluid combination. The augmented convection heat transfer results are higher than the thermal conductivity of nanofluids [11]. Numerous research papers, such as twisted tape inserts with Al_2O_3-water nanofluid, have reported on the use of nanofluid in conjunction with heat transfer enhancement [12]. The heat transmission of an Al_2O_3-water nanofluid in a conduit was estimated using a neural network. Heat transmission is shown to increase as the concentration of nanoparticles rises [13]. The maximum increase in Nusselt number with Al_2O_3 was 57% (Re = 3704), with a pressure drop of 39% and a volume percentage of 1.5 [14]. Nanofluids were prepared with a range of 0.2 to 1 wt.% of nanoparticles. Further, the CuO/CMC-based nanofluid gives a better performance than the other two fluids. The heat transfer was increased at high nanofluid concentration, shell side temperature, stirrer speed, and Dean number (De) [15]. Oil-based CuO nanofluid with laminar flow in plain tube demonstrated a 45% increase in heat transmission and a 63% increase in pressure drop [16]. The experimental results show that the performance boost of CuO nanofluid with coil insert is more than that of twisted tape [17]. The new empirical design was developed in the correlation with Reynolds number and compared with the already existing one. The new mathematical equation was formed as Nu = 0.8 Re = 0.56 Pr = 0.333($\mu/\mu w$) 0.14 for a chevron angle of 60° [18]. The Reynolds number of nanofluids was observed between 3000 and 12000 and found to increase in NTU and effectiveness. The increased pressure drops in the shell and tube sides, on the other hand, were 40.7% and 51.9%, respectively [19]. The alumina nanofluid gives a superior thermal performance of 3.1% greater than deionized water when using the range of ϕ = 2% at Re = 1800 than ZnO-water nanofluid besides [20]. In a helical copper heat exchanger, the nanofluids are used to determine the enhancement of the heat transfer at constant wall temperature. At higher Reynolds numbers, the heat transfer coefficient and Nusselt number are increased due to the agglomeration reduction of ZnO nanoparticles [21]. The erosive wear is determined by nanoparticle size, impinge velocity, shape, particle concentration, angle of attack, and fluid temperature. It is also discovered that there are no significant health risks other than MWCNT irritation when exposed to bare skin [22]. The effects of nanoparticle mixture ratio, inlet temperature and flow rate, and Al_2O_3-MWCNT nanofluid energetic and exergetic performance in plate heat exchangers were discovered to increase with an increase in MWCNT ratio mixture [23]. Using MWCNT nanofluid with particle volume concentrations of 0.1%, 0.3%, and 0.5%, the pressure drop and heat transfer of a cone helical coiled heat exchanger were analyzed under the Dean number range of 2200 < De < 4200, the pressure drops of nanofluids increased by 16%, 30%, and 42%, respectively, as did heat transfer enhancement by 28%, 52%, and 68% [24]. The pressure drop and convective heat transfer coefficient of Al_2O_3-water nanoparticles in an evenly heated circular tube in a completely developed laminar temperature regime were measured. At 0.3% volume concentration, the convective heat transfer coefficient increased by up to 8%. Furthermore, they proposed Brownian diffusion and thermophoresis as potential processes for improving convective heat transmission [25]. The pressure drop and overall heat transfer coefficient of Al_2O_3-water nanoparticles were 0.1%, 0.4%, and 0.8%, respectively, under laminar flow volume concentrations of 0.1%, 0.4%, and 0.8%. At a volume concentration of 0.8%, the highest interior heat transfer coefficient was discovered to be 24.6%. Overall heat transfer occurred at 24.2% in a volume concentration of 0.8%. And the whole test was performed in the $1600 < De_i < 2700$ range under laminar flow conditions [26, 27].

As per previous investigations, no major work has been carried out with helically coiled heat exchangers on convergent-divergent sections. In addition, the alumina nanofluid has been used for the further enhancement of heat transfer. This research aims to analyze the overall heat transfer coefficient, inner heat transfer coefficient (shell fluid to tube fluid) and Nusselt number for CDHCT with water and nanofluid. The field emission scanning electron microscope (FESEM) was used to check nanoparticle deposition in the inner surface of the tube.

The main intention of this exploration is to analyze the experimental overall heat transfer coefficients of convergent and divergent helical coiled tube heat exchangers with Al_2O_3-water nanofluid. This investigation is done by different nanoparticle volume concentrations such as 0.1 vol.%, 0.3 vol.%, and 0.5 vol.%. The dispersion of nanoparticles in deionized water was prepared with the required concentration using an ultrasonic bath which produced pulses of 100 W at 36.3 kHz for 4 hours to obtain uniform dispersion and stable suspension. To keep the nanoparticles stable in the base fluid, a surfactant was added.

Materials and methods

Figure 1 depicts the experimental work handle with a convergent-divergent cone helical coiled tube. Figure 2 depicts the schematic layout of the complete experimental design. This experimental set-up consists of two loops. One is the shell side and the other is the CD helical coil tube. The cold nanofluid-flows through the coil side and the hot water flows through the shell side. The shell side is attached to a storage container measuring 15 cm × 15 cm × 15 cm and powered by a 2 kW magnetic pump. Further, the inlet temperature of the hot fluid is monitored with the help of a thermostat. The CD helical coiled tube is connected to a 0.5 hp monoblock pump through a flow control valve. The pump is connected to a nanofluid storage tank. The CD helical coil tube winding is done by using the wooden pattern shown in fig. 1. Before winding, the inner side of the tube is filled with fine sand to avoid inner surface distortion. The tube is manufactured of copper, and the shell is made of CPVC. The thermostat is used to gauge the temperature of hot water in a shell storage vessel, whereas the temperature of the shell outlet and inlet is measured with four *K*-type thermocouples and a CD helical coiled side with an accuracy of 0.1 °C of the thermocouple. The surface temperature of the coil is measured with the help of three *K*-type thermocouples, which are fitted on the outer surface of the tube wall by using pasted with epoxy for leakage prevention. The claiming section is provided to avoid the entrance effort in the CD helical coiled tube. In this case, the *U*-tube Mercury manometer is fitted across. However, 1 m and 0.003 are the values of the uncertainty of the mercury manometer. The shell was insulated with the help of asbestos tape with a thickness of 10 mm. Normally, the control valves are provided in the flow pipe. Hot nanofluids will be cooled by using a cooling unit. The water was circulated to examine the experimental set-up and find the leaks, assuring its functions and fittings. The dimensions of the test section of convergent-divergent helical coil tube angle –4°, CD coil inner tube diameter, d_i – 8 mm, coil outer tube diameter, d_o – 10 mm, the effective length of the coil, L – 6500 mm, coil pitch, b – 20 mm, CD coil mean diameter is D – 77 mm, and shell diameter – 114 mm.

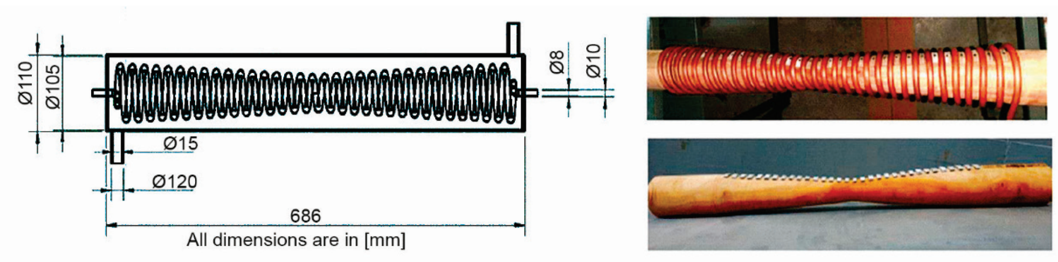

Figure 1. Copper coil on convergent-divergent section

The CDHCT angle was kept constant throughout the test run, with hot water flowing through the shell side and cold water flowing through the CD helical coil side, respectively, using an external pump to pump the hot and cold fluid. The hot water was kept at its temperature using a thermostat. The hot water flowed through the shell side and the cold nano-fluid flowed through the CD helical coil tube, with the shell side maintaining a constant flow rate of 0.16 kg/s and the nanofluid-flow rate ranging between 0.01 and 0.05 kg/s [4-6].

After the flowing, fluid had reached its steady state, the temperature was measured. The fluid-flow rates were manually measured by collecting the fluid in a precise measuring jar and keeping a stopwatch going. The experimental tests were carried out in the Dean number range of 1100 < De < 4200. The pressure drop was measured using a *U*-tube manometer. Due to measurement inaccuracies, there is uncertainty surrounding every quantity that was measured in order to estimate the tube side Nusselt number.

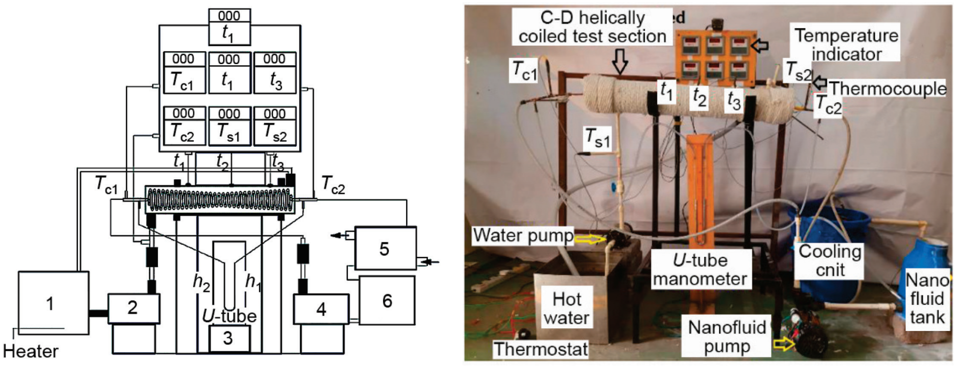

Figure 2. Convergent and divergent helically coiled tube heat exchanger set-up; *1 – water storage pump, 2 – water pump, 3 – manometer, 54 – nanofluid pump, 5 – cooling unit, and 6 – nanofluid storage tank*

Nanofluid preparation

The Al_2O_3 nanoparticle Alumina (Alpha) Nanopowder was provided by Sisco Research Laboratories Pvt. Ltd., in Mumbai. The Al_2O_3 is a white powder, and it is characterized with the help of EDAX as shown in fig. 3 (EDAX Make: BRUKER (GERMAN), MODEL: Nano X Flash Detector). The particle size ranges between 20-30 nm on average. In this study, Al_2O_3-water based nanofluid was created by incorporating the desired concentration of Al_2O_3 nanoparticles into the base fluid in two steps.

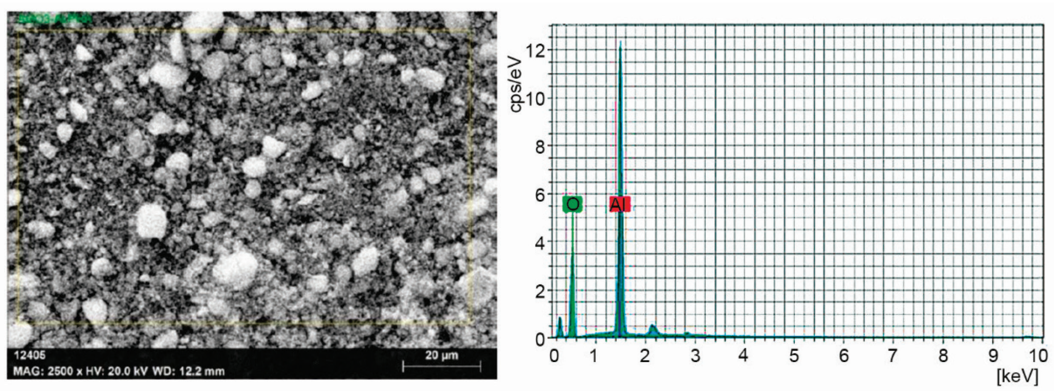

Figure 3. The EDAX for Alumina (Alpha) nanopowder (Al_2O_3)

The Al_2O_3 nanoparticles were taken as the required amount and were scattered in the distilled water by using an ultrasonic bath (Citizen, India). To achieve stable nanoparticle suspension and uniform distribution, it generates the ultrasonic pulses at 110 W at 40 ±5kHz for four hours using the ultrasonicator shown in fig. 4. The two-step method provides less agglomeration and greater stability [4, 21]. The Al_2O_3 water-based nanofluid was prepared at 0.1 vol.%, 0.3 vol.%, and 0.5 vol.% concentrations [24], and the image of the Al_2O_3 suspended nanofluid revealed that the particles were uniformly dispersed in the base fluid, as shown by the typical FESEM image in fig. 6. Figure 5 shows that, under the static conditions of nanofluid, it was found that there is no apparent settlement of nanoparticles after 30 days from the day of preparation. In order to maintain the nanoparticles in the baseline at a consistent level, SDBS is added as a surfactant [28].

Figure 4. Ultrasonic sonicator

Figure 5. Nanofluid samples

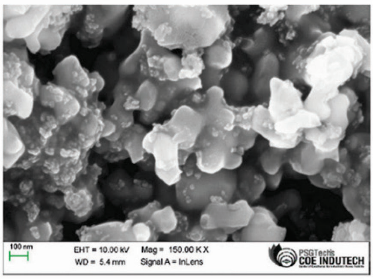

Figure 6. The Al_2O_3 suspended nanofluid

Parameters prediction

The following techniques are used to calculate the thermophysical characteristics of an Al_2O_3-water nanofluid at different volume concentrations. These parameters include density, viscosity, specific heat, and thermal conductivity, eqs. (1)-(6).

The density of nanofluid [kgm^{-3}]:

$$\rho_{\mathrm{nf}} = \phi\rho_{\mathrm{p}} + (1-\phi)\rho_{\mathrm{f}} \tag{1}$$

where ρ_{nf} is the nanofluid density, ρ_{p} – the particle density, and ϕ – the vol.%.

Specific heat of nanofluid [Jkg^{-1}K^{-1}]:

$$(\rho c_p)_{\mathrm{nf}} = (1-\phi)(\rho c_p)_{\mathrm{f}} + \phi(\rho c_p)_{\mathrm{p}} \tag{2}$$

where c_p is the specific heat capacity and ρ – the density.

Nanofluid effective thermal conductivity in [Wm^{-1}K^{-1}]:

$$k_{\mathrm{nf}} = k_{\mathrm{f}}\left[1 + \frac{k_{\mathrm{p}}\phi r_{\mathrm{f}}}{k_{\mathrm{f}}(1-\phi)r_p}\right] \tag{3}$$

where k is the thermal conductivity, p – the particle, f – the fluid, r_p – the nanoparticle size, and ϕ – the vol.%

During the nanofluid-flow, the following parameters are mainly focused on determining, eqs. (4)-(9) the flow effectiveness.

Dean number:

$$\mathrm{De} = \mathrm{Re}_i \left(\frac{d_i}{2R_c} \right)^{0.5} \tag{4}$$

Heat transfer by water:

$$Q_{bf} = m_{bf} c_{p_{bf}} (T_{\mathrm{in}} - T_{\mathrm{out}})_{bf} \tag{5}$$

Heat transfer by nanofluid:

$$Q_{\mathrm{nf}} = m_{\mathrm{nf}} c_{p,\mathrm{nf}} (T_{\mathrm{in}} - T_{\mathrm{out}})_{\mathrm{nf}} \tag{6}$$

Overall heat transfer:

$$Q = U_{\mathrm{o}} A_{\mathrm{o}} (\Delta T) \tag{7}$$

Inner heat transfer:

$$Q = h_{\mathrm{i}} A_{\mathrm{i}} (T_{\mathrm{wall}} - T_{\mathrm{bulk}}) \tag{8}$$

Nusselt number:

$$\mathrm{Nu}_i = \frac{h_i d_i}{k_{\mathrm{eff}}} \tag{9}$$

Result and discussion

Heat transfer enhancement

The convergent-divergent helically coiled tube heat exchanger was tested with Al_2O_3 nanofluid under different volume concentrations. The test was conducted for different mass-flow rates of nanofluid (cold side). The observations and findings such as the inner heat transfer coefficient, overall heat transfer coefficient, and Nusselt number are presented in the following section.

Figure 7 shows how increasing Dean number and particle volume concentration results in an improvement in the overall heat transfer coefficient. At 0.1 vol.%, 0.3 vol.%, and 0.5 vol.%, it was discovered that the overall heat transfer coefficient was enhanced by up to 27%, 55%, and 78% in comparison to water. The overall heat transfer was increased with the increase of the Dean number. The maximum was found with De = 4100, which is about 78% with 0.5 vol.%. It is mainly due to the fluid inside the coil having a higher heat transfer rate and a lower temperature drop than the fluid inside the shell side. The curvature effect in fluid motion was enhanced in the convergent and divergent sections, which caused the enhancement of the heat transfer rate. The increase in nanoparticle concentration results in a faster heat transfer rate due to the higher thermal conductivity of the nanofluid [2, 4-6].

Increased particle volume concentration has an impact on the inner heat transfer coefficient, as seen in fig. 8. It is clear that as the inner Dean number rises, the tube side heat transfer coefficient rises as well. When 0.1 vol.%, 0.3 vol.%, and 0.5 vol.% were compared to water, the enhancement of tube side inner heat transfer coefficients at fixed inner Dean number was found to be up to 24%, 55%, and 78%. The reason is that the higher heat transfer rate and lower temperature drop by increasing Dean number are because of the curvature effect of the tube. The enhancement by increasing nanoparticle concentration is due to the higher heat transfer rate caused by the higher thermal conductivity of nanofluid.

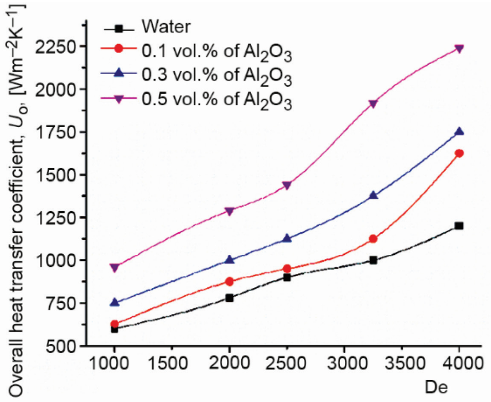

Figure 7. Overall heat transfer coefficient

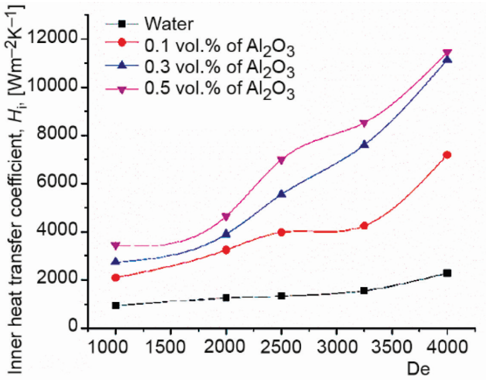

Figure 8. Inner heat transfer coefficient

Increased particle volume concentration has an impact on the inner heat transfer coefficient, as seen in fig. 8. It is clear that as the inner Dean number rises, the tube side heat transfer coefficient rises as well. When 0.1 vol.%, 0.3 vol.%, and 0.5 vol.% were compared to water, the enhancement of tube side inner heat transfer coefficients at fixed inner Dean number was found to be up to 24%, 55%, and 78%. The reason is that the higher heat transfer rate and lower temperature drop by increasing Dean number are because of the curvature effect of the tube. The enhancement by increasing nanoparticle concentration is due to the higher heat transfer rate caused by the higher thermal conductivity of nanofluid.

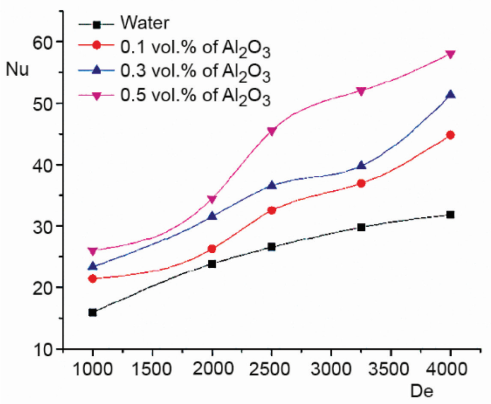

Figure 9. Nusselt number *vs.* Dean number

These findings show that the maximum inner heat transfer coefficient was found to be 78% at Dean number of 4100 with 0.5 vol.%. It is evident that the rate of heat transfer increased as the particle volume concentration increased, just as the secondary flow motion and convergent-divergent action had a greater impact on the rate of heat transfer [4-6]. Figure 9 depicts the effect of varying the inner Dean number on the inner Nusselt number. The Dean number was increased in line with the Nusselt number. The maximum value of Nusselt number was noted at about 27%, 51%, and 72% at 0.1 vol.%, 0.3 vol.%, and 0.5 vol.% as compared with water. These increments are because of the decrement of the temperature difference between the wall and the bulk fluid temperature of the nanofluid. The reduction of wall temperature occurs when nanoparticles hit the wall surfaces. If the particle volume concentration is higher than the optimum, it is expected that the heat transfer coefficient may decrease due to the effect of increased viscosity at a high particle volume concentration.

Table 1 shows the comparative perception of overall heat transfer and inner heat transfer with optimal dean number between our findings and similar previous findings. As compared with others, CDHC with Al_2O_3 nanofluid produced a good heat transfer rate in both the overall and inner coil. The results indicate that the heat transfer was found efficient at a higher Dean number, where the higher secondary flow and Brownian effect occurred. There are three reasons for better heat conduction. Nanosized particles have a positive effect on secondary flow formation in a convergent-divergent helical tube. The increased thermal conductivity, Brownian effect, and improved fluid mixing of nanoparticles are the reasons for this improvement. Furthermore, the addition of nanoparticles had no negative effect on fluid centrifugal force, viscous force, or inertia force [3, 4-6]. Also, an increase in thermal conductivity and random motion of nanoparticles could improve the Nusselt number.

Table 1. Comparison of results with other investigations

	Volume concentration	Overall heat transfer coefficient [$Wm^{-2}K^{-1}$]	Inner heat transfer coefficient [$Wm^{-2}K^{-1}$]	Dean number	Reference
MWCNT-water nanofluids	0.5%	1100	6250	4200	[24]
Al_2O_3-water nanofluid under laminar flow condition	0.8%	1225	4410	2600	[26]
Al_2O_3-water nanofluid	0.5%	2248	11910	4100	–

Surface morphology of Cu-tube inner surface before and after the experimental test

The convergent-divergent helically coiled tube heat exchanger test was conducted for different mass-flow rates of Al_2O_3 nanofluid. The coil material was copper. Hence, there is a possibility of deposition in the inner tube of CDHCT due to the flow of nanofluid with a different volume of concentration. The nanoparticles have surface contact with the inner side of the tube. Figures 10 and 11 showed the cut section of the Cu-tube before and after the experimentation. It obviously shows that nanoparticle deposition was found in the wall after the test was done.

Similarly, the surface morphology of the inner tube was checked by FESEM (CARL ZEISS (USA), MODEL: SIGMA WITH GEMINI COLUMN, Resolution 1.5 nm) before and after the test was conducted. FESEM images as shown in figs. 12 and 13, respectively with 25 k magnification. The surface morphology has been analyzed as per ASM standard [29].

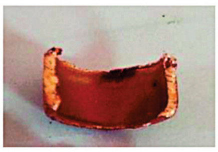

Figure 10. Tube before nanofluid-flow

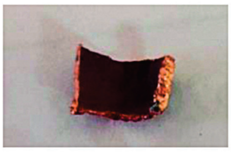

Figure 11. Tube after nanofluid-flow

Figure 12 depicts how the Cu-tube inner surface seems before the experimental run. Obviously, the Cu-tube is mostly used in the heat exchanger to achieve better heat transfer enhancement [4-6]. Also, nanofluids are mostly used in heat exchangers to enhance heat transfer. Hence, using nanofluid in the exchanger, there was surface sedimentation found in the inner tube due to particles present in the nanofluids having contact with the inner tube surface.

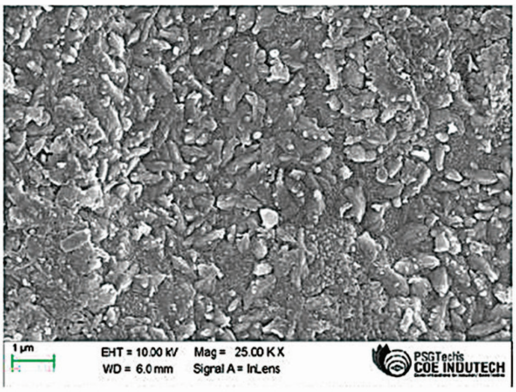

Figure 12. Tube before nanofluid-flow FESEM

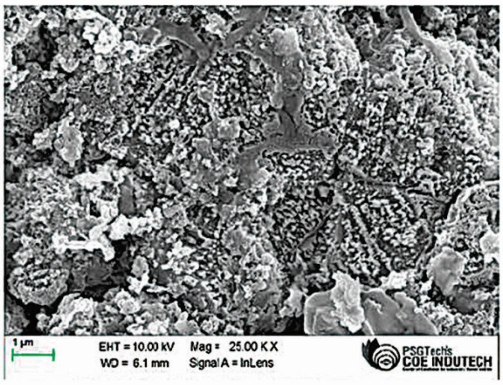

Figure 13. Tube after nanofluid-flow FESEM

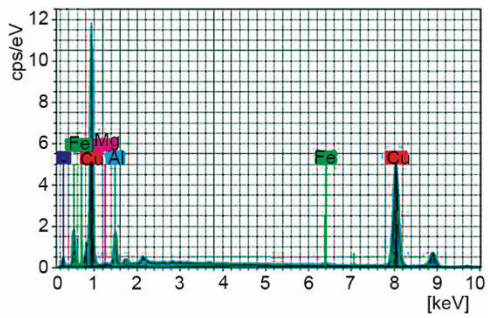

Figure 14. The EDAX for Cu-tube inner side after flow

As shown in fig. 13, the effect of deposition on the inner surface of the Cu-tube while using nanofluids was maintained between 0.01 kg/s to 0.05 kg/s with the three different vol.% concentrations of 0.1%, 0.3%, and 0.5%. Figure 13 indicates the effect of sedimentation on the inner side of the tube. The surface morphology of the Cu-tube changed after the completion of the entire experimental run. The presence of nanoparticles on the inner side of the tube surface was identified by using the elemental analysis EDAX (BRUKER (GERMAN)) shown in fig. 14. The Al_2O_3 nanoparticles were present on the inner surface of the Cu-tube after the 48 hours experimental run of three different vol.% concentrations of nanofluid with a mass-flow rate range between 0.01 kg/s and 0.05 kg/s. It was found that the nanoparticles on the inner tube surface were present with 4.63 wt.% of alumina due to the sedimentation on the inner surface.

Conclusions

In this study, the Al_2O_3-water nanofluid was used to improve heat transfer in a helically coiled convergent-divergent tube heat exchanger. As per test results, it has been evidenced that the use of a helically coiled convergent-divergent tube heat exchanger with nanofluid tends to improve heat transfer more than water does. It focuses on the increase in heat transfer coefficient with increasing nanoparticle volume concentration and internal Dean number.

- It was concluded that the Dean number and particle concentration increased, and the inner heat transfer coefficient improved. This is due to secondary flow inducement and enhancement of the thermal conductivity of nanofluid. The greatest enhancement in the inner heat transfer coefficient was seen at 78% compared to water at 0.5 vol.% and De = 4100

- It was also observed that as the Dean number and particle concentration increased, so did the overall heat transfer coefficient. This is also because of secondary flow enhancement and high thermal conduction.
- The maximum overall heat transfer coefficient was found to be 78% compared to water at 0.5 vol.% and De = 4100.
- The Nusselt number increased as the Dean number increased, indicating that secondary flow and the Brownian effect influenced heat transfer enhancement in the helically and convergent-divergent sections.
- Inducing the convergent-divergent section on the helical coil heat exchanger improves the heat transfer rate significantly compared with the helical coil tube heat exchanger.
- The optimal volume concentration of Al_2O_3 is 0.5 vol.% and the flow rate is 0.05 kg/s. Beyond 0.5 vol.%, the pressure drop may increase which will reduce the heat transfer coefficient.
- By using EDAX (elemental analysis), it was found that the 4.63 wt.% of alumina nanoparticle was deposited over the inner surface of the copper tube of the coil.

Nomenclature

CDHCT – convergent/divergent helically coiled tube
EDAX – elemental dispersion analysis
MWCNT – multi-walled carbon nanotubes
HTC – heat transfer coefficient
SDBS – sodium dodecyl benzenesulfonate
CPVC – chlorinated polyvinyl chloride
FESEM – field emission scanning electron microscope

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Paper submitted: December 5, 2022
Paper revised: June 1, 2023
Paper accepted: June 12, 2023