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

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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 Al2O3/water nanofluid. The nanofluid was prepared using a two-stage technique with proportions of 0.1vol%, 0.3vol%, and 0.5vol%. 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 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 Al2O3/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 Al2O3/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.

Keywords: Convergent-divergent helically coiled tube (CDHCT), Nanofluid, Al2O3, Heat transfer coefficient

1. 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, 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 (CCHEx) without any nano-fluid combination. The exploration setup includes fifteen coils of cone angles of 135°, 90°, 45°, 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 nano-fluid it further increased [3]. The heat transmission and pressure decrease in helically coiled tube heat transfer working fluid as Al₂O₃ 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 Al₂O₃ nano-fluid 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 nano-fluid. 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 nano-fluid and nano-fluid preparation were done by using two-step methods by adding SDS surfactant. From the result, it was concluded that the max 45% in OHTC, 52% in IHTC, and 56% in INN is higher than water at a concentration of 0.5% volume [5]. In a double helically coiled tube heat exchanger using MWCNT nano-fluid, 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 nano-fluid with a 0 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/m² °C, and the HTC for Re = 1895 is 544.46 W/m² °C [8]. The pressure drop and HTC are directly proportional to the curvature ratio and Reynolds number. Also, using CuO as a nano-fluid, 16-17% HTC increases and 14-16% pressure drop increases were noted compared to water [9]. The heat transfer was increased with different nano-fluids 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 SiO₂ nano-fluid and 41.82% in Al₂O₃ nano-fluid combination. The augmented convection heat transfer results are higher than the thermal conductivity of nano-fluids [11]. Numerous research papers,
such as twisted tape inserts with Al$_2$O$_3$/water nanofluid, have reported on the use of nanofluid in conjunction with heat transfer enhancement [12]. The heat transmission of an Al$_2$O$_3$/H$_2$O 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$_2$O$_3$ 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 1wt% 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 [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(µ/µw) 0.14 for a chevron angle of 60° [18]. The Reynolds number of nanofluids was observed between 3000 – 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 DI water when using the range of $\phi = 2\%$ 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, imping 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$_2$O$_3$-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$_2$O$_3$ /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$_2$O$_3$/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<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
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$_2$O$_3$/water nanofluid. This investigation is done by different nanoparticle volume concentrations such as 0.1vol%, 0.3vol%, and 0.5vol%. 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.

2.1 Materials and Methods

Fig 1 depicts the experimental work handle with a convergent-divergent cone helical coiled tube. Fig 2 depicts the schematic layout of the complete experimental design. This experimental setup 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 15cm x 15cm x 15cm 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 0.5hp 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 fig1. 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 setup and find the leaks, assuring its functions and fittings. The dimensions of the test section of convergent-divergent helical coil tube angle -4 degrees, 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, shell diameter – 114 mm.

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/sec and the nanofluid flow rate ranging between 0.01 and 0.05 kg/sec [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.

![Copper coil on convergent-divergent section](image)

**Figure 1. Copper coil on convergent-divergent section**
2.2 Nanofluid Preparation

Al₂O₃ nanoparticle Alumina (Alpha) Nanopowder was provided by Sisco Research Laboratories Pvt. Ltd., in Mumbai. Al₂O₃ is a white powder, and it is characterized with the help of EDAX as shown in Fig 3.
The particle size ranges between 20 nm - 30 nm on average. In this study, Al$_2$O$_3$ water-based nanofluid was created by incorporating the desired concentration of Al$_2$O$_3$ nanoparticles into the base fluid in two steps. The Al$_2$O$_3$ 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 4 hours using the ultrasonicator shown in Fig 4. The two-step method provides less agglomeration and greater stability [4, 21]. The Al$_2$O$_3$ water-based nanofluid was prepared at 0.1vol%, 0.3vol%, and 0.5vol% concentrations [24], and the image of the Al$_2$O$_3$ suspended nanofluid revealed that the particles were uniformly dispersed in the base fluid, as shown by the typical FESEM image in fig 6. Fig 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, sodium dodecyl benzenesulfonate (SDBS) is added as a surfactant [28].

![EDAX Make: BRUKER (GERMAN), MODEL: Nano X Flash Detector.](image1)

**Figure 3. EDAX for Alumina (Alpha) Nano powder (Al$_2$O$_3$).**

![Ultrasonic Sonicator](image2)

![Nanofluid samples](image3)

![Al$_2$O$_3$ Suspended nanofluid](image4)

**Figure 4. Ultrasonic Sonicator**  **Figure 5. Nanofluid samples**  **Figure 6. Al$_2$O$_3$ Suspended nanofluid**

**2.3 Parameters Prediction**

The following techniques are used to calculate the thermophysical characteristics of an Al$_2$O$_3$/water nanofluid at different volume concentrations. These parameters include density, viscosity, specific heat, and thermal conductivity [equ 1-6].
The density of nanofluid in kg/m³

\[ \rho_{nf} = \phi \rho_p + (1-\phi) \rho_f \]  

Where,
\( \rho \) – density, \( nf \) – nanofluid, \( p \) – particle, \( \emptyset \) – Vol%

Specific Heat of nanofluid J/kg K

\[ (\rho_c p)_{nf} = (1-\phi)(\rho_c p)_f + \phi(\rho_c p)_p \]  

Where,
\( C_p \) - specific heat capacity, \( \rho \) – density

Nanofluid's effective thermal conductivity in W/mK is,

\[ k_{nf} = \frac{k_f + \frac{k_p \phi r_f}{k_f (1-\phi) r_p}}{1} \]  

Where,
\( k \) - Thermal conductivity, \( p \) – particle, \( f \) – fluid, \( r_p \) - nanoparticle size, \( \emptyset \) – Vol%

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

Dean Number

\[ D_e = \text{Re} \left( \frac{d_i}{2R_c} \right)^{0.5} \]  

Heat transfer by water

\[ Q_{bf} = m_{bf} c_p \rho_{bf} (T_{in} - T_{out})_{bf} \]  

Heat transfer by nanofluid

\[ Q_{nf} = m_{nf} c_{nf} \rho_{nf} (T_{in} - T_{out})_{nf} \]  

Overall heat transfer

\[ Q = U_{h} A_{i} (\Delta T) \]  

Inner heat transfer

\[ Q = h_i A_i (T_{wall} - T_{bulk}) \]  

Nusselt number

\[ Nu_i = \frac{h_i d_i}{k_{eff}} \]

3. Result and Discussion

3.1 Heat Transfer Enhancement

The convergent-divergent helically coiled tube heat exchanger was tested with Al₂O₃ nanofluid under different volume concentrations. The test was conducted for different mass flow rates of nanofluid
The observations and findings such as the inner heat transfer coefficient, overall heat transfer coefficient, and Nusselt number are presented in the following section.

Fig 7 shows how increasing Dean Number and particle volume concentration results in an improvement in the overall heat transfer coefficient. At 0.1vol%, 0.3vol%, and 0.5vol%, 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 0.5vol%. 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].

![Figure 7. Overall heat transfer co-efficient](image)
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.

These findings show that the maximum inner heat transfer coefficient was found to be 78% at De of 4100 with 0.5vol%. 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]. Fig 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 Nu was noted at about 27%, 51%, and 72% at 0.1vol%, 0.3vol%, and 0.5vol% 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 nano-fluid. 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 Comparison of results with other investigations

<table>
<thead>
<tr>
<th></th>
<th>Volume Concentration</th>
<th>Overall Heat Transfer Co-Efficient (W/m²K)</th>
<th>Inner Heat Transfer Co-Efficient (W/m²K)</th>
<th>Dean Number (De)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-wall carbon nanotube (MWCNT) / water nanofluids</td>
<td>0.5 %</td>
<td>1100</td>
<td>6250</td>
<td>4200</td>
<td>[24]</td>
</tr>
<tr>
<td>Al₂O₃ / water nanofluid Under laminar flow condition</td>
<td>0.8%</td>
<td>1225</td>
<td>4410</td>
<td>2600</td>
<td>[26]</td>
</tr>
<tr>
<td>Al₂O₃ / water nanofluid</td>
<td>0.5%</td>
<td>2248</td>
<td>11910</td>
<td>4100</td>
<td>-</td>
</tr>
</tbody>
</table>

![Figure 9: Nusselt number vs dean number](image)

**Figure 9. Nusselt number vs dean number**

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 Al₂O₃ 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: 1. Nano-sized particles have a positive effect on secondary flow formation in a convergent-divergent helical tube. 2. The increased thermal conductivity, Brownian effect, and improved fluid mixing of nanoparticles are the reasons for this improvement. Furthermore, 3. 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.

3.2 Surface Morphology of Copper 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 Al₂O₃ 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. Fig 10 and Fig 11 showed the cut section of the copper 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 Fig 12 and Fig 13, respectively with 25k magnification. The surface morphology has been analyzed as per ASM standard [29].

<table>
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<tr>
<th>Figure 10. Tube before nanofluid flow</th>
<th>Figure 11. Tube after nanofluid flow</th>
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Fig 12 depicts how the copper tube inner surface seems before the experimental run. Obviously, the copper 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.
As shown in Fig 13, the effect of deposition on the inner surface of the copper tube while using nanofluids was maintained between 0.01 to 0.05 kg/sec with the three different vol% concentrations of 0.1%, 0.3% and 0.5%. Fig 13 indicates the effect of sedimentation on the inner side of the tube. The surface morphology of the copper 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 Al₂O₃ nanoparticles were present on the inner surface of the copper tube after the 48-hour experimental run of three different vol% concentrations of nanofluid with a mass flow rate range between 0.01 and 0.05 kg/sec. 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.

4. Conclusion

In this study, the Al₂O₃/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 De 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 0.5vol% and De=4100.
- It was also observed that as the De 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 0.5vol% 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 Al₂O₃ is 0.5vol% and the flow rate is 0.05 kg/s. Beyond 0.5vol%, the pressure drop may increase which will reduce the heat transfer coefficient.
- By using EDAX (elemental analysis), it was found that the 4.63wt.% of alumina nanoparticle was deposited over the inner surface of the copper tube of the coil.

Nomenclature

1. Al₂O₃ - Aluminum Oxide (Alumina Nanoparticle)
2. CDHCT - Convergent Divergent Helically Coiled tube
3. CCHE - Conical Coil Heat Exchanger
4. EDAX - Elemental Dispersion Analysis
5. MWCNT - Multi-Walled Carbon Nano Tubes
6. HTC - Heat Transfer Coefficient
7. SDBS - Sodium Dodecyl benzenesulfonate
8. CPVC - Chlorinated Polyvinyl Chloride
9. FESEM - Field Emission Scanning Electron Microscope

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