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# Study of Heat Transfer and Pressure Drop Inside Helical Cone Tube

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**Abstract.** The present work is devoted to numerically investigate the characteristics of the convective heat transfer and pressure drop of pure water in the helicalcone tube with different taper angel inside cylindrical shell working as a shell and tube heat exchanger. This work is performed at different geometrical parameters of the HCTs and at different operating conditions for the tube side of the heat exchanger. Three helical cone tube (HCT) heat exchangers of counter-flow configurations are constructed with different torsions, and tapper angles. Wilson plot method is used to investigate the thermal performance results in terms of tube average heat transfer coefficient, average Nusselt number and Fanning friction factor are presented. The results showed that the conical tube heat exchangers have lower heat transfer coefficient and lower friction factor compared with that in helical.

## Nomenclature

| **Symbols** | **Definition** |
|---|---|
| $\dot{m}$ | Mass Flow Rate, kg/s |
| $\mu_t$ | Dynamic Viscosity, kg/m.s |
| Cp | Specific heat, J/kg.°C |
| De | Dean Number |
| d | Diameter, m |
| h | Convection Heat Transfer coefficient, W/m$^2$.ºC |
| c | Cross sectional |
| Nu | Nusselt Number |
| P | Pressure, Pa |
| p | Pitch, m |
| m | Mean |
| Re | Reynolds number |
| S | Coil Spacing, m |
| U | Overall heat transfer, W/m$^2$.ºC |

**Letters**

| | |
|---|---|
| $\Delta$ | Differential |
| $\theta$ | Cone angle |
| $\mu$ | Dynamic viscosity |
| $\rho$ | Density |

**Scripts**

| | |
|---|---|
| an | Annulus |
| eq | Equivalent |
| i | Inner or inlet or internal |
| L | Logarithmic mean |

## 1. INTRODUCTION

Heat exchangers are widely used in a lot of applications, like chemical processing, nuclear reactors, power plants, heat recovery systems, food industries and in refrigeration and air-conditioning systems. The improvement of heat transfer coefficient has two important outcomes in the heat exchangers. Firstly, it basically improves the performance and secondly reduces the size of the heat exchanger. In applications, many techniques are used to improve the heat transfer and are classified into two types as active and passive techniques. Coiled tube configuration in heat exchangers is the one of the most important passive heat transfer improvement techniques [1, 2], due to high heat transfer coefficient and compact structure.

Helical coiled configuration is very effective for some heat transfer equipmentsuch as heat exchangers [3, 4] and reactors because in small space (volume) they accommodate a large heat transfer area. The curvature in tube induces secondary flow patterns [5] due to centrifugal force developed in the fluid when the fluid is flowing through the curved tube.For the same flow rate, these secondaries allow mixing of the fluid that enhances the heat transfer coefficient, whereas pressure drop across the coiled tube increases due to these secondaries. It was noted by Shah and Joshi [6], that the enhancement depends on the intensity of secondary developed in the coiled tube. In case of smaller coil diameter and tube diameters (D and d) the intensity of secondary flow developed is high. Eustice [7] was the first to observe the fluid motion in curved pipes. Since then many researchers presented their studies on the fluid flow that develop in curved pipes, including helical coils [2, 8]. They provided the flow fields and temperature field analysis experimentally and numerically. The major effects observed in the helical coil configuration were due to the flow pattern in the curved tube; hence it is very essential to understand the effect of the flow pattern in curved tubes.

Prabhanjan et al. [9] performed the comparative study of the heat transfer between straight tube and helical coil tube in liquid to liquid configuration and showed that the helical coil heat exchangers show higher heat transfer coefficient. Thermal performance of a helical heat exchanger was investigated by Jung-Yang Sen et al. [10]. The helical coil heat exchanger was considered for the analysis with rectangular cross section and cover plates with inside mixed flow and the flow was unmixed on outside the tube. The analysis was carried out to study the behavior of friction factor and heat transfer coefficient.

The analysis of water-water heat exchanger was carried out with numerical model by Fernandez-Seara et al. [11] with outer surface in natural convection. The analysis was validated with experimental data with two helical coil heat exchangers tested under same operating conditions and the analysis showed that the Nu increases with the increase in tube diameter. Lee et al. [12] also studied the buoyancy forces with constant heat flux on fully developed laminar flow effect in the flow field and Thermal field. The system for fully developed laminar flow was numerically analyzed with constant heat flux along the axis and constant wall temperature condition along periphery. They found that average Nu was affected by buoyancy. They also found that the rotation of the secondary flow patterns depends on the buoyancy forces. Padmanabhan [13] studied the entry flow into curved pipes for constant heat flux and for constant wall temperature condition axially. The secondary motion was affected by buoyancy

The investigation on concentric helical coils heat exchangers were experimentally investigated by Gomaa et al. [14] for its thermodynamic and hydrodynamic characteristics. Various parameters were considered for study as coil curvature ratio, number of turns, flow configuration, and addition of surface. The results showed that the annulus Nu was affected by annulus curvature ratio, δ and number of turns in such way the Nu has direct relation with annulus curvature ratio, δ and inverse relation with number of turns. Similar relation was obtained with friction factor, and noted that it increases with curvature ratio, δ and decreases with number of turns. In the analysis of tube in tube helical coil heat exchanger Mandal and Nigam [15] studied the transfer and fluid flow under turbulent condition. For both side in the heat exchanger water was used as working fluid. The tube side operating condition of inside tube was as Re in the range of 14,000 to 86,000. The data was validated by CFD analysis. Salem et al.

[16-18] conduct a series of experimental investigations on a horizontal shell and coil heat exchanger. In [16], the investigated the effect of coil curvature on the thermal performance and developed correlations to predict the average Nusselt number in the tube and shell side in addition to the Fanning friction factor in the tube side.

The present work is devoted to investigate numerically the characteristics of the convective heat transfer and pressure drop of helical cone heat exchangers of counter-flow configurations. This work is performed at different geometrical parameters of the HCT and at different operating conditions for the internal side of the heat exchanger

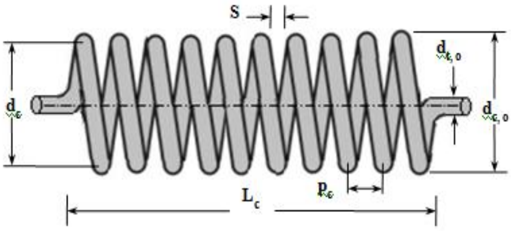

Fig 1: Basic geometry of an HCT.

## 2.1Physical Modeling of heat exchanger

The HCT heat exchangers that modeled numerically consist of helical coiled tube placed inside cylindrical shell. In the present study, the hot fluid flows in the cylindricalshell, while the cold fluid flows in the conical tube in counter flow configuration. The simulation tool, ANSYS-FLUENT 14.5 CFD commercial package is used and the governing equations are solved for flow, temperature and pressure values for each cell.

The geometry used for CFD modeling of HCT heat exchangers with inner coiled tubeare shown in Fig. 1. The coilsare constructed from inner cone tube with different tapper angels inside the cylindrical outer shell. The coils are modeled in the counter flow configuration, where the cold fluid (water) flows in the coiled tube with inlet temperature, ti=10 to 25 °C while the hot fluid (air) flows in the outer shell with inlet temperature 50 °C. The diameterof the inner tube is 10 mm. The outer cylindrical shelldiameter (D), length (L) is 300 mm, 1 m, respectively. The inner tubeis coiled to form HCT heat exchanger with outer shell, Dc=100 mm, coil pitch, H=10 mm. Three coil inclination angles, θ=0°,22.5°, and 45° are simulated and N is no of turns for the coil. The details of the used coils are presented in Table 1.

**Table 1: Characteristic dimensions of the used coils.**

| Coil No. | $d_{t,i}$ (mm) | $d_{t,o}$ (mm) | $D_{sh,i}$(mm) | $L_t$ (mm) | $D_{c,min}$(mm) | H (mm) | θ | λ | N |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 10.92 | 12.7 | 300 | 5000 | 119.05 | 10 | 0° | 0.0641 | 14 |
| 2 | | | | | | 20 | 22.5° | 0.0924 | 10 |
| 3 | | | | | | 30 | 45° | 0.1206 | 8 |

A high-quality meshing is very important for more successful numerical of simulations. The smaller the size of elements near the wall of the tube, the more detailed and also accurate flow structure will be captured. However, for 3-dimensional simulation, a small change in elements size leads to a substantial increase in number of elements, which leads to remarkable increase in the computational time. Therefore, for making a convenient balance between the accuracy of the simulations and solution time, an optimum size of mesh needs to be chosen.

A tetrahedral method is used for meshing the shell and tube domains with relevance center of medium type and fine smoothing. Skewness is one mesh metrics, available in ANSYS; the acceptable range for Skewness is between 0.8 and 0.95. This range is considered in the existing simulation study to get mesh with a high quality. The Range of both fluids operating conditions which used in numerical analysis after creating the model with smooth meshing, are listed in Table 2.

**Table 2: Range of both fluids operating conditions.**

| Parameters/operating conditions | Range or Value |
|---|---|
| **Tube-side** | |
| Water velocity, m/s | 0.1, 0.2, 0.3, 0.4 &0.5 |
| Inlet temperature, °C | 10, 15, 20, 25 |
| **Shell-side** | |
| Air velocity, m/s | 0.5 |
| Inlet temperature, °C | 50 |

## Results and discussion

In the present work represents the effect of tapper angel, water inlet boundary conditions (temperature and velocity)on heat transfer rate. Fig.2showsthe temperature contours for the tree coils with different tapper angels 0, 22.5 and 45.From the fig it can be deduced that for air side as the tapper angel increases the air temperature will decrease comparison with the helical one and for water side the outlet temperature will increase in comparison with the helical one due to vortices so increasing tapper angel will increase the heat transfer rate but it was observe that the pressure drop will increase also along the coil fig.3 Comparison of pressure contours for different models with different tapper angels and also fig.4 Comparison of velocity contours for different models with different tapper angels.

**Effect of changing tapper angel**

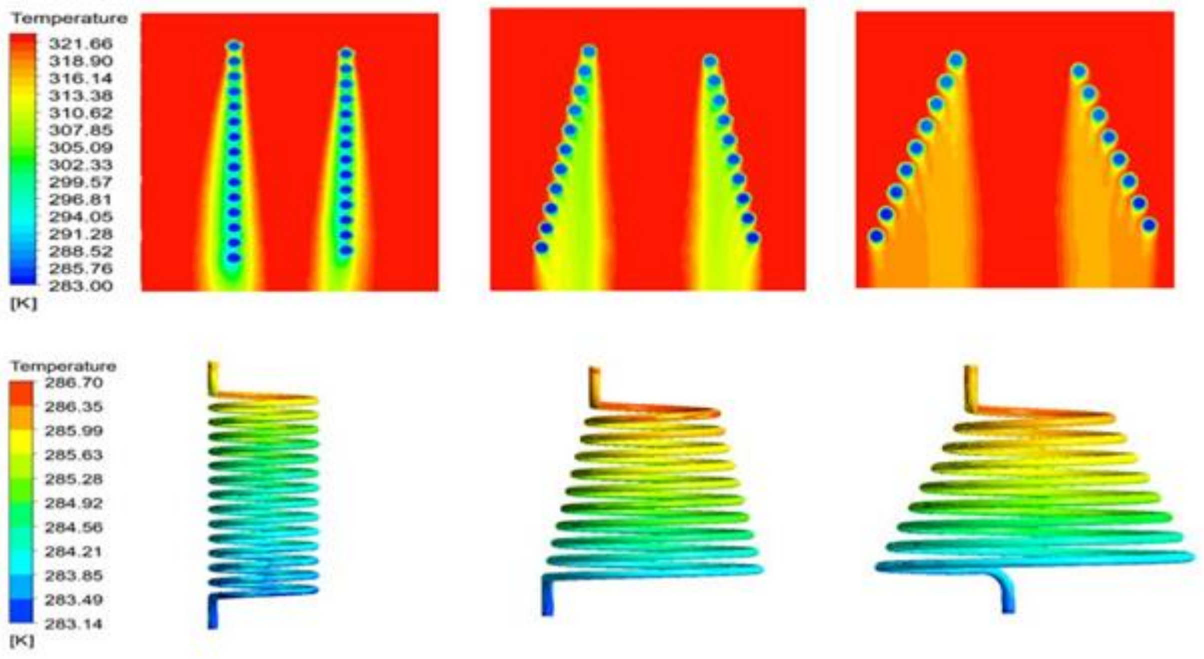

Fig.2 Comparison of temperature contours for different models with different tapper angel

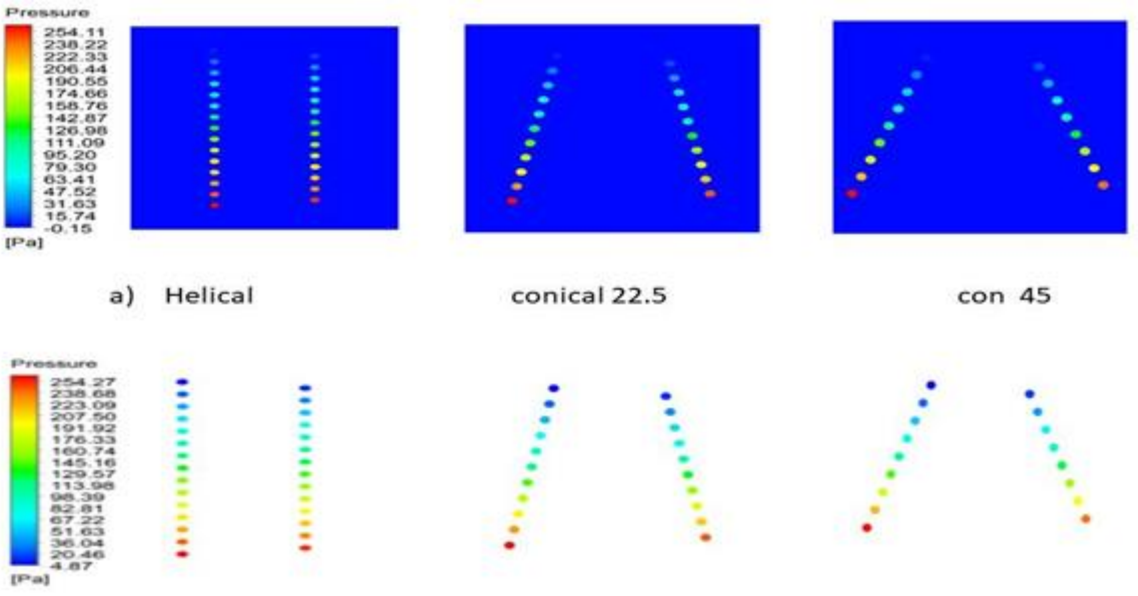

Fig.3Comparison of pressure contours for different models with different tapper angel

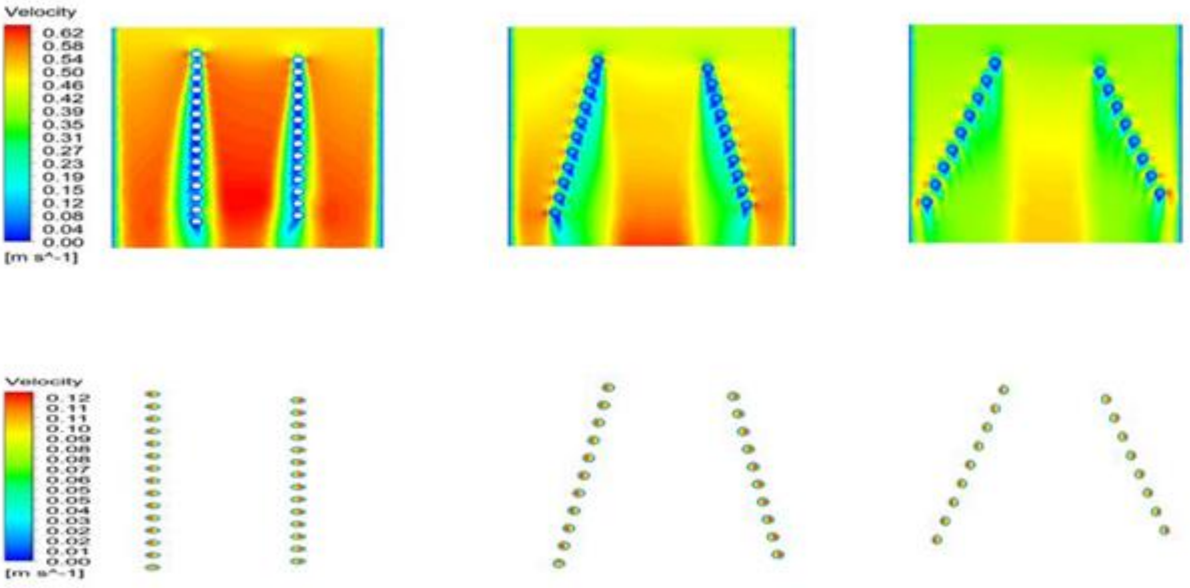

Fig.4 Comparison of velocity contours for different models with different tapper angel

## Effect of changing water inlet temperature

For the other side fig.5 effect of changing inlet water temperature it was deduced that the by increasing the inlet water temperature the outlet temperature for air side will be decreased and for water side will be decreased so increasing water inlet temperature will decrease the rate.

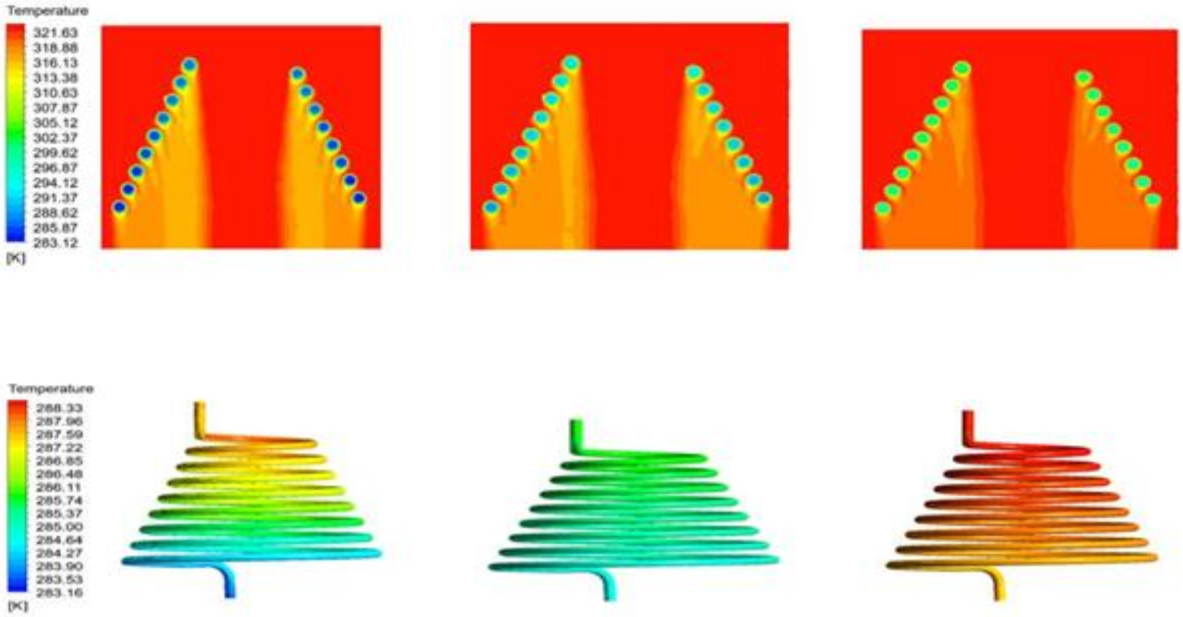

Fig.5 Comparison of temperature contours for different models with different water inlet temp.

## Effect of changing water inlet Velocity

For fig.6 Comparison of temperature contours for different models with different water inlet velocity as observed in the fig. by increasing the inlet water velocity the heat transfer rate will be increased in comparison with the helical one at the same condition.

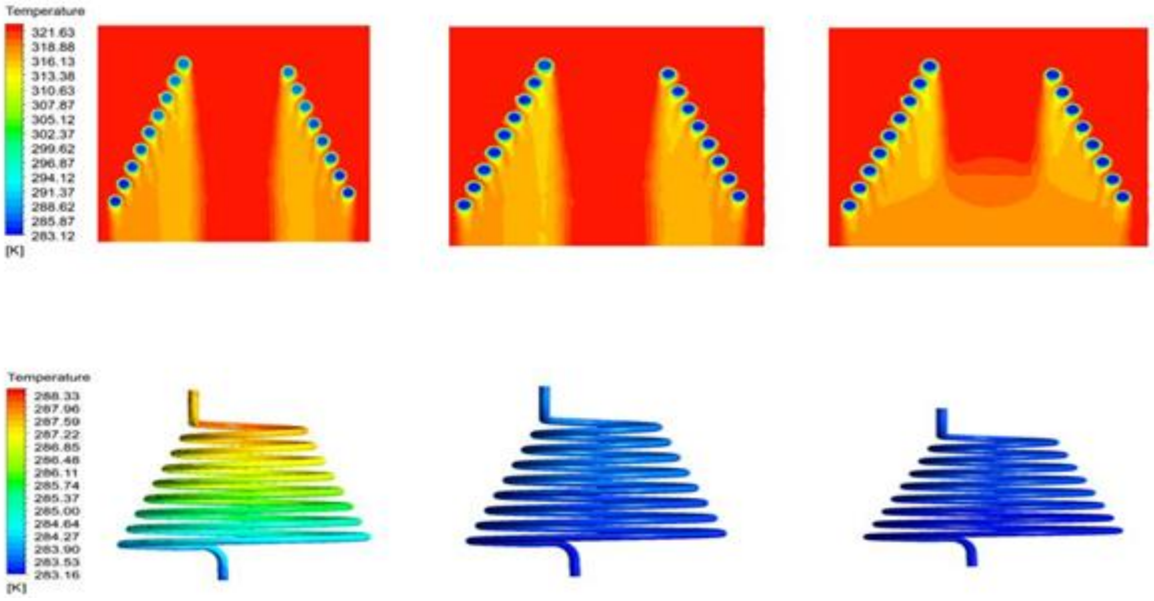

Fig.6 Comparison of temperature contours for different models with different water inlet velocity.

## 4. Conclusions

Numerical CFD simulations with Realizable k–ϵ turbulence model are employed in the present work. The effect of changing in Reynolds number, flow rate, tapper angel and inlettemperature on the heat transfer and friction factor for fluid flow inside helical cone tube. The major conclusions drawn from this work can be summarized as following:

- Increasing tapper angel will increase heat transfer rate
- Increasing tapper angel will increase pressure drop
- Increasing inlet temperature will decrease the heat transfer rate.
- Increasing inlet velocity will increase the heat transfer rate.
- Increasing inlet velocity will increase the pressure drop.

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