

EVALUATION OF THERMAL PERFORMANCE OF CONE SHAPED HELICAL COIL HEAT EXCHANGER BY USING CFD ANALYSIS

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ABSTRACT:

Now-a-days, Helical Coil Heat Exchangers find a prominent role in industrial applications for the better performance. Its configuration is most effective over Shell and Tube heat exchangers for higher heat transfer rates. An attempt is made in the paper to evaluate the performance of Cone Shaped Helical Coil Heat Exchanger (HCHE) by comparing with that of Simple type. CATIA V5 software is used to model both the helical coils. The pitch and height of both the coils are kept identical for analysis. The material of Shell and Coil is assigned Steel and Copper respectively. The models are exported to Autodesk CFD 2015 software for Meshing and Analysis.

Then Computational Fluid Dynamics (CFD) Analysis is carried-out for various flow rates of 40, 60, 80, 100, 140 LPH at Coil side and constant rate of 200 LPH at Shell side under steady state conditions by using K- ϵ Turbulence Model. The Convergence of Simulation of the Simple and Cone Shaped Helical Coil Heat Exchanger is performed for better results. The results and contours are drawn for temperature and velocity by considering the above flow rates. At 40 LPH, it is observed that the temperature decrement of 29.14°C in Coil of Conical HCHE is greater than 26.72°C which is obtained in Simple HCHE. Also, the Heat Transfer rate of 1454.08 W for the Cone Shaped HCHE is higher over Simple HCHE of 1208.14 W. Further it is observed that the heat transfer rates of Cone shaped HCHE are increased by 10-20% with respect to the Simple HCHE.

KEYWORDS: CATIA V5, Autodesk CFD, Convergence, K- ϵ Turbulence Model

I. INTRODUCTION

Heat Exchangers are the most commonly used equipment in Power stations and Petroleum refining plants. A Heat Exchanger is a device used to transfer thermal energy between two or more fluids at different temperatures over a solid surface when they are in thermal contact.

The most common type of Heat Exchanger that is being used is Shell and Tube Heat Exchanger which consists of series alignment of tubes. In contrary to this design, the Helical Coils have been

used in different applications due to easiness in manufacture. Due to the curved structure of tube, centrifugal forces are developed which help in the increment of both the friction factor and Heat transfer Coefficients.

II. LITERATURE REVIEW

Timothy John Rennie [1], has studied the heat transfer characteristics of Helical Coil Heat Exchanger for both parallel and counter flow. The results obtained from the simulations were overall heat transfer coefficients determined for Dean Numbers ranging from 38 to 350. **Jundika C. Kurnia et al [2]**, have evaluated the heat transfer performance of helical coils of non-circular tubes. They have investigated the performances of Helical, in-plane Spiral and Conical configurations and compared to the straight duct. It was found that Coiled ducts would give higher heat transfer rates. **Daniel Flórez-Orrego et al [3]**, have studied the nature of Single phase Cone shaped Helical Coil Heat Exchanger. He proposed that even though velocity contours were similar, an appreciable deviation of the velocity vector components in the secondary flow was observed. **Shinde Digvijay D and Dange H. M [4]**, have conducted the experimental research on Simple and Cone Shaped Helical Coil Heat Exchangers considering the counter flow. The boundary conditions of hot water and cold water mass flow rates were taken. For the flow rates ranging from 60 LPH and 280 LPH characteristics were determined. They found that varying Coil side flow rate has impact on the performance of Heat Exchanger. The study showed that Conical Helical Coil Heat Exchanger has better performance over Simple helical type.

OBJECTIVE OF THE PAPER:

An attempt is made in this paper to design and perform the analysis of Cone shaped Helical

Coil Heat Exchanger and compare with that of Simple type. The models are created by using CATIA V5. By applying the boundary conditions, meshing and CFD analysis is carried-out in Autodesk CFD software.

IV. MODELING

III. DATA COLLECTION

Table.1 Geometrical dimensions for HCHE

S.No	Parameters	Units	Dimensions	
			Simple Helical Coil	Cone Shaped Helical Coil
1.	Copper tube Outer Diameter	mm	9.53	9.53
2.	Copper tube Inner Diameter	mm	8.41	8.41
3.	Top Coil Diameter	mm	210	75
4.	Bottom Coil Diameter	mm	210	210
5.	Coil Height, H	mm	170	170
6.	Pitch of the coil	mm	20	20
7.	Shell Outer Diameter	mm	270	270
8.	Shell Inner Diameter	mm	260	260
9.	Height of the Shell	mm	250	250

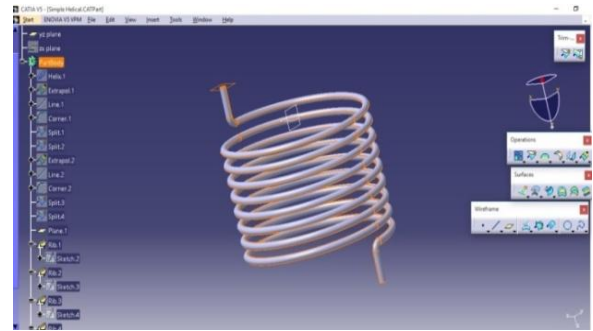


Fig.1 Design of Helical Coil

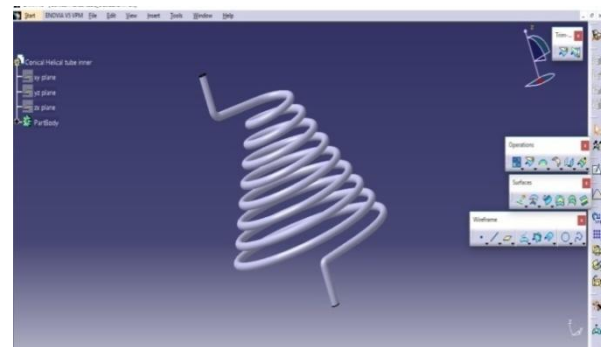


Fig.2 Design of Conical Helical Coil

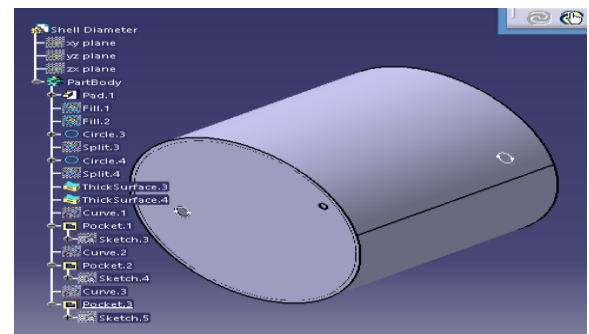


Fig.3 Design of Shell

Table.2 Fluid and Material Properties

S. No	Material	Density (Kg/m ³)	Specific Heat (J/kg K)	Thermal Conductivity (W/mK)
1.	Hot Fluid	974	4195	0.6687
2.	Cold fluid	1000	4182	0.6129
3.	Coil	8940	381	386
4.	Outer Shell	7833	465	53.5

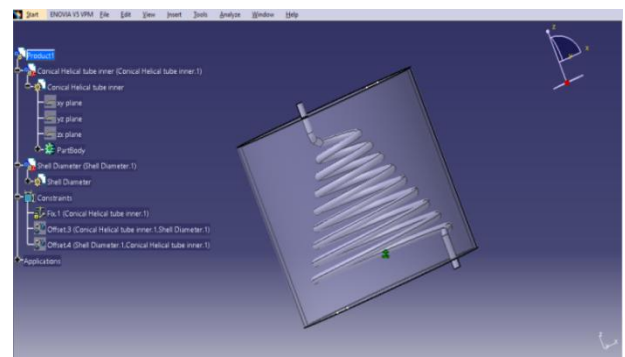


Fig.4 Assembly of Cone Shaped Helical Coil Heat Exchanger

V. MESHING

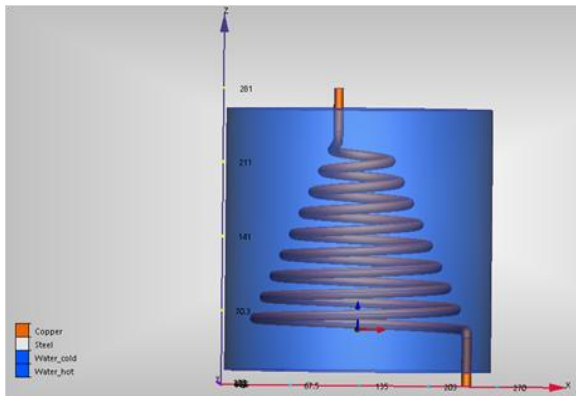


Fig.5 Material Selection in CFD

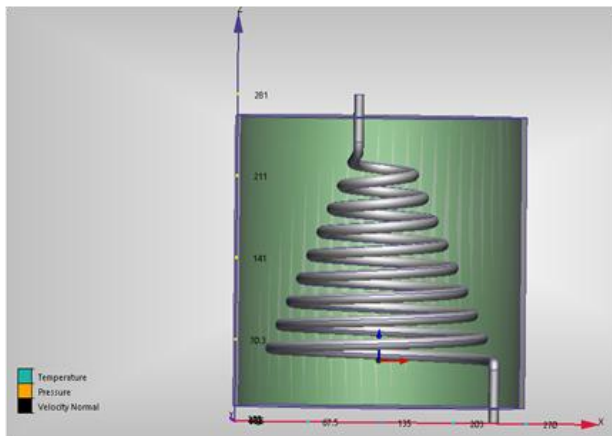


Fig.6 Applying Boundary Conditions

The meshing of Simple and Conical Helical Coil Heat Exchanger was done using Steady state Solution mode & K- ϵ Turbulence Model.

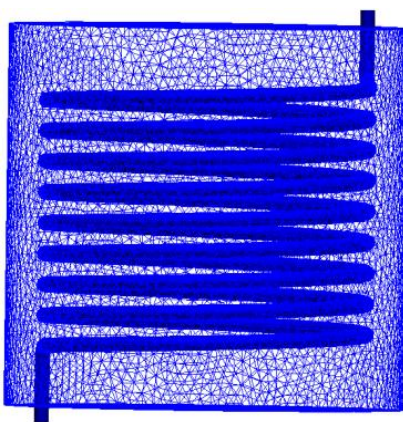


Fig.7 Meshed Simple HCHE

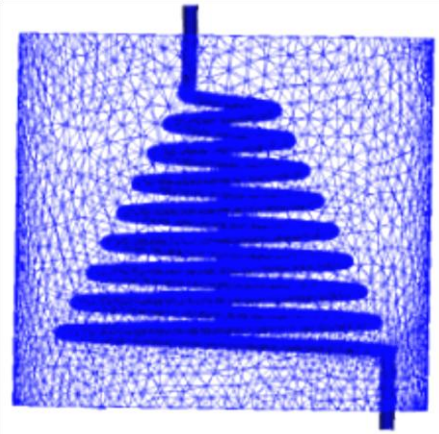


Fig.8 Meshed Conical HCHE

VI. CFD ANALYSIS

For Flow rates of 40, 60, 80, 100 and 140 LPH, Reynolds Number for Simple HCHE are observed as 1421, 2082, 2844, 3470, 4859.5 and for Conical HCHE, Reynolds number of 1338.5, 2008, 2677, 3349, 4685 respectively are observed. At the flow rate of 40 LPH, Laminar flow is observed while for the remaining flow rates, Turbulence Condition is observed during the flow of fluid.

At 40 LPH:

Temperature Contours:

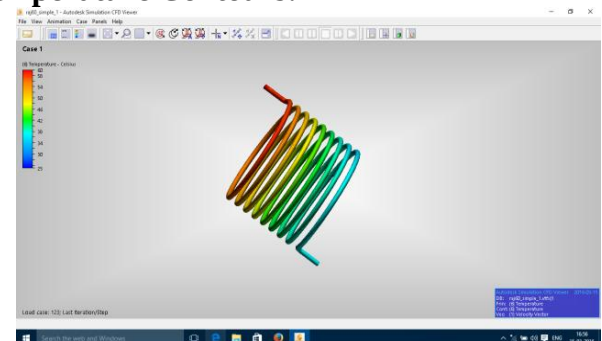


Fig.9 In Coil of Simple HCHE at 40 LPH

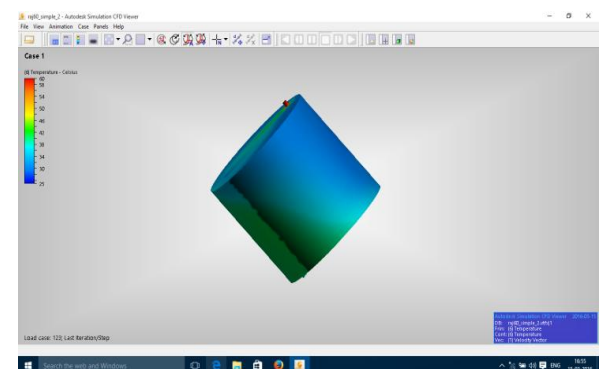


Fig.10 In Shell of Simple HCHE at 40 LPH

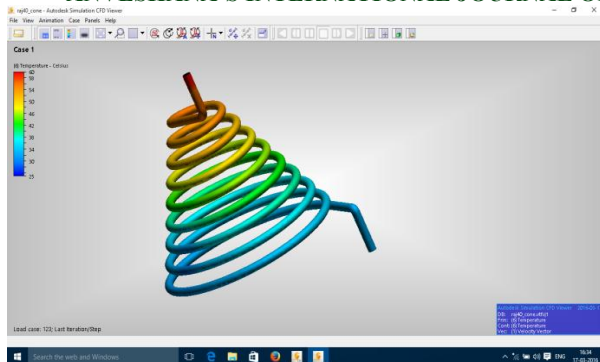


Fig.11 In Coil of Conical HCHE at 40 LPH

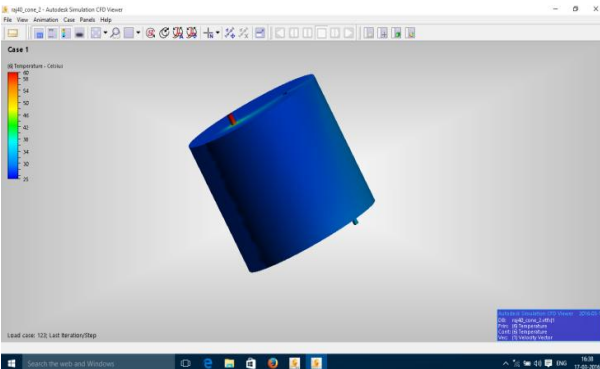


Fig.12 In Shell of Conical HCHE at 40 LPH

Velocity Contours:

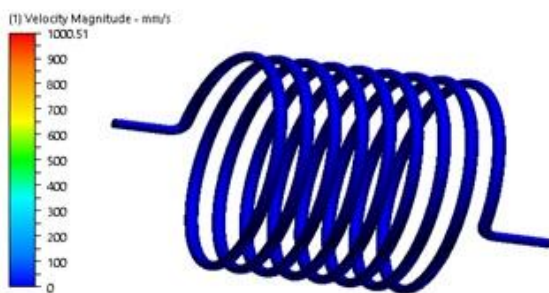


Fig.13 in Coil of Simple HCHE at 40 LPH

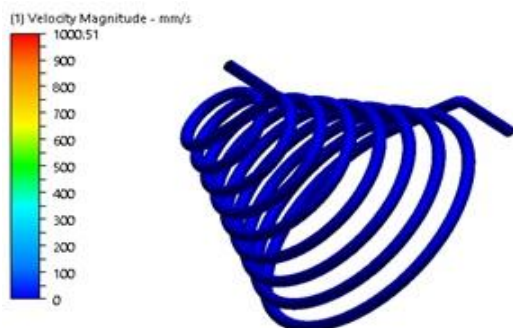


Fig.14 in Coil of Conical HCHE at 40 LPH

At 80 LPH:

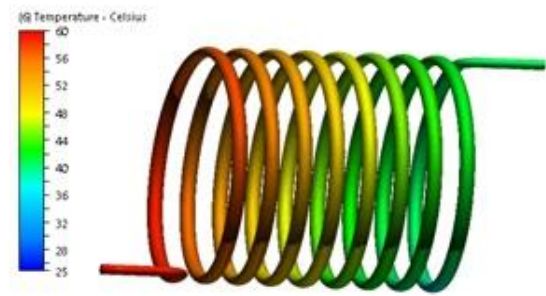


Fig.15 Temperature distribution in Coil of Simple HCHE at 80 LPH

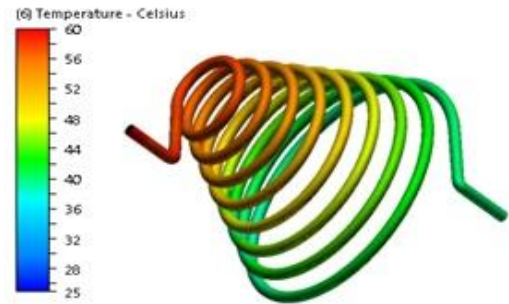


Fig.16 Temperature distribution in Coil of Conical HCHE at 80 LPH

Analytical Solution for the Flow Rate of 80 LPH: Simple HCHE:

1. Heat Transfer Rate (Q_{Avg})

$$Q_h = m_h C_{ph} (T_{hi} - T_{ho}) = 0.021 \times 4195 \times (60 - 40.6) = 1709.04 \text{ W}$$

$$Q_c = m_c C_{pc} (T_{co} - T_{ci}) = 0.053 \times 4182 \times (33.52 - 25) = 1899.11 \text{ W}$$

$$Q_{Avg} = \frac{Q_h + Q_c}{2} = 1804.07 \text{ W}$$

2. Overall Heat Transfer Coefficient (U)

$$U = \frac{Q}{A \cdot LMTD} = \frac{1804.07}{(3.14 \times 0.00953 \times 6.096) \times 20.56} = 481.02 \text{ W/m}^2\text{K}$$

3. Dean Number (De)

$De = Re \sqrt{d/D}$ where: Re is the Reynolds Number, d is the tube diameter, and D is the Coil Diameter

$$= 2844 \times \sqrt{8.41/210} = 569$$

4. Effectiveness (ϵ)

$$Q_{max} = m_h C_{ph} (T_{hi} - T_{ci}) = 0.021 \times 4195 \times (60 - 25) = 3083.325 \text{ W}$$

$$Q_{act} = m_h C_{ph} (T_{hi} - T_{ho}) = 0.021 \times 4195 \times (60 - 40.6) = 1709.04 \text{ W}$$

$$\epsilon = \frac{Q_{act}}{Q_{max}} = \frac{1709.04}{3083.325} = 0.55$$

Conical HCHE:

$$Q_{act} = 1790.01 \text{ W}$$

1. Heat Transfer Rate (Q_{Avg})

$$Q_h = 0.0197 \times 4195 \times (60 - 38.34) = 1790.01 \text{ W}$$

$$Q_c = 0.0512 \times 4182 \times (35.97 - 25) = 2348.88 \text{ W}$$

$$Q_{Avg} = 2069.45 \text{ W}$$

2. Overall Heat Transfer Coefficient (U)

$$U = \frac{Q}{A \cdot LMTD} = \frac{2069.45}{(3.14 \times 0.00953 \times 6.096) \times 18.16} = 624.7 \text{ W/m}^2\text{K}$$

3. Dean Number (De)

$$De = Re \sqrt{d/D} = 650$$

4. Effectiveness (ϵ)

$$Q_{max} = 2892.45 \text{ W}$$

$$\epsilon = \frac{Q_{act}}{Q_{max}} = \frac{1790.01}{2892.45} = 0.62$$

The Critical Reynolds number, Re_{cr} is calculated by the below equation considering curvature ratio for the coils:

$$Re_{cr} = 2100 (1 + 12 \lambda^{0.5})$$

It is found as 8222 for cone shaped helical coil and 7143 for simple helical coil.

VII. RESULTS

The below table shows the CFD temperature results in Coil and Shell sides for various flow rates.

Table.3 Temperature Results

S.NO	FLOW RATE	SIMPLE HCHE				CONICAL HCHE			
		SHELL		COIL		SHELL		COIL	
		INLET	OUTLET	INLET	OUTLET	INLET	OUTLET	INLET	OUTLET
1.	40	25	30.56	60	33.28	25	32.93	60	30.86
2.	60	25	32.09	60	37.15	25	33.99	60	35.94
3.	80	25	33.52	60	40.6	25	35.97	60	38.34
4.	100	25	35.24	60	41.5	25	37.86	60	41.06
5.	140	25	36.91	60	44.94	25	39.49	60	42.87

Table.4 Heat Transfer Rates for Various Flow Rates

S. No.	Flow rate (LPH)	Heat Transfer Rate (W) (SIMPLE)	Heat Transfer Rate (W) (CONICAL)	Percentage increase (%)
1.	40	1208.14	1454.08	20.35
2.	60	1523.48	1709.36	12.20
3.	80	1804.07	2069.45	14.71
4.	100	2134.63	2358.03	10.46
5.	140	2458.24	2794.48	13.67

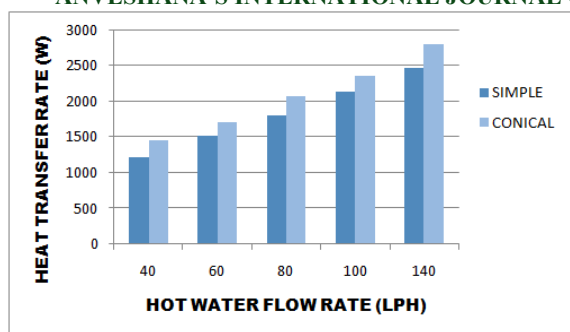


Fig.17 Heat Transfer rate Vs Hot Water Flow rate

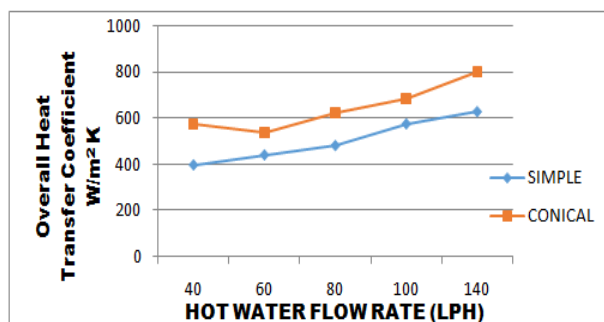


Fig.18 Overall Heat Transfer Coefficient Vs Hot Water Flow rate

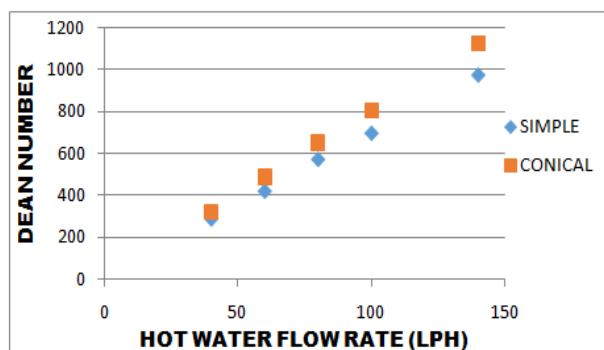


Fig.19 Dean Number Vs Hot Water Flow rate

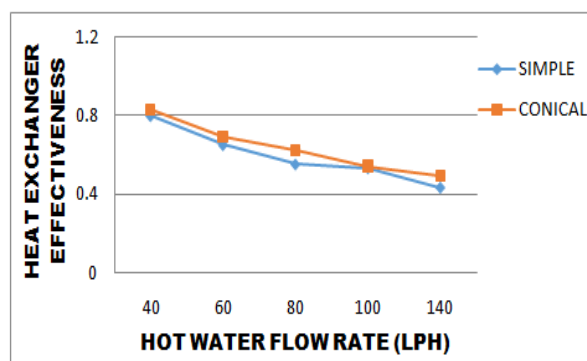


Fig.20 Effectiveness Vs Hot Water Flow rate

VIII. CONCLUSIONS

1. From the results analysis, it was observed that temperature is reduced to a great extent in Conical HCHE at the flow rate of 40 LPH.
2. It was observed that Cone Shaped Helical Coil Heat Exchanger possesses better Heat Transfer characteristics than Simple HCHE.
3. The Heat transfer rate increases with increase in Flow rate at Coil side. In Conical HCHE at 40 and 80 LPH, the Heat transfer rate is increased by 20.35% and 14.71% respectively. At higher flow rates of 100 LPH and 140 LPH, there has been not much increase in the Heat transfer.
4. The Overall Heat transfer Coefficient increases with increase in Flow rate at Coil side. At 60 LPH, it got decreased due to the less turbulence. The better Coefficient obtained at 140 LPH.
5. The Dean Number is an important characteristic in configuration of Helical Coils which is the function of Reynolds Number. More the Dean Number, the better is the performance of Heat Exchanger. The Reynolds Number is high in case of Simple HCHE but Dean Number is greater in case of Conical HCHE because of the modified design.
6. The Heat Exchanger Effectiveness is decreased considerably with increase in Coil side flow rate. Cone Shaped Helical Coil Heat Exchanger has greater Effectiveness of 0.83 at 40 LPH than that of 0.8 in Simple HCHE.

FUTURE WORK:

In the present paper, the CFD analysis is carried out in order to evaluate the thermal performance of Simple and Cone Shaped Helical Coil Heat Exchangers by just modifying the design providing an inclination angle of around 65° considering the Flow rate boundary conditions. The extension of this work can be done for different inclination angles and varying pitch.

IX. REFERENCES

- [1] Timothy John Rennie, "Numerical And Experimental Studies of a Double pipe Helical Heat Exchanger," Dept. of Bio-resource Engg. McGill University, Montreal August, (2004)
- [2] Jundika C. Kurnia, Agus P. Sasmito, Arun S. Mujumdar, "Evaluation of the heat transfer performance of helical coils of non circular tubes,"

- [3] **Daniel Flórez-Orrego, Walter Arias, Diego López and Héctor Velásquez**, “*Experimental and CFD study of a single phase cone-shaped helical coiled heat exchanger: an empirical correlation*,” Proceedings of ECOS 2012 - The 25th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, June 26-29, Perugia, Italy (2012)
- [4] **Shinde Digvijay D and Dange H. M.**, “*Heat Transfer Analysis of a Cone Shaped Helical Coil Heat Exchanger*,” (IJET), Vol. 3 Issue 1 October (2013)

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