International Journal of Science and Research (IJSR)
ISSN: 2319-7064
ResearchGate Impact Factor (2018): 0.28 | SJIF (2019): 7.583

CFD Analysis of Heat Transfer in a Helical HX With Elliptical Cross Section in Liquid Medium

Saria Sayeed[1], **Pooja Tiwari**[2]

[1]Master's Student, Mechanical Engineering, Shriram Institute of Technology, Jabalpur, India

[2]Assistant Professor, Mechanical Engineering, Shriram Institute of Technology, Jabalpur, India

Abstract: ***The objective of this research is to deals with the analysis of the helical coiled heat exchanger (circular and elliptical cross section) with various correlations given by different papers for specific conditions. A heat exchanger is a device that is used to transfer thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact. The complex fluid-dynamic inside curved pipe heat exchangers gives them important advantages over the performance of straight tubes in terms of area/volume ratio and enhancing of heat transfer and mass transfer coefficient. The analysis of these various correlations with certain defined data is presented in this project. In this study, an attempt has been made to analyze the effect of counter-flow on the total heat transfer from a helical tube. The temperature contours, velocity vectors, surface nusselt number, total heat transfer rate from the wall of the tube was calculated and plotted using ANSYS 16.1. The fluid flowing through the inner tube and outer casing was taken as water***.

Keywords: Helical Heat Exchanger, Ansys Fluent, helical heat flow, Elliptical tube layout, Heat Transfer, Numerical Method, Nusselt

1. Introduction

Many engineering systems, including power plants, climate control, and engine cooling systems typically contain tubular heat exchangers. However, for most engineering problems, it is impractical to model individual fins and tubes of a heat exchanger core. In principle, heat exchanger cores introduce a pressure drop to the primary fluid stream and transfer heat from or to a second fluid (such as a coolant), referred to here as the auxiliary fluid. A heat exchanger is a heat transfer device that exchanges heat between two or more process fluids. Heat exchangers have widespread industrial and domestic applications. Many types of heat exchangers have been developed for use in steam power plants, chemical processing plants, building heat and air conditioning systems, transportation power systems, and refrigeration units the purpose of constructing a heat exchanger is to get an efficient method of heat transfer from one fluid to another, by direct contact or by indirect contact. The actual design of heat exchangers is a complicated problem. It involves more than heat-transfer analysis alone. Cost of fabrication and installation, weight, and size play important roles in the selection of the final design from a total cost of ownership point of view.

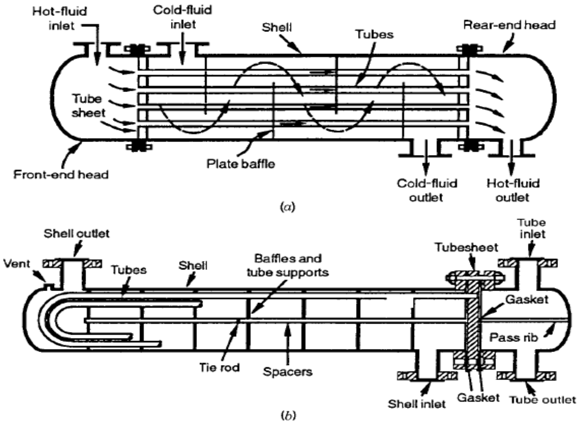


Figure 1.1: (a) Shell-and-tube exchanger (BEM) with one shell pass and one tube pass; (b) shelland-tube exchanger (BEU) with one shell pass and two tube passes

The heat transfer occurs by three principles: conduction, convection and radiation. The conduction mode of heat transport occurs either because of an exchange of energy from one molecule to another, without the actual motion of the molecules, or because of the motion of any free electrons that are present. Therefore, this form of heat transport depends heavily on the properties of the medium and takes place in solids, liquids and gases if a difference in temperature exists.

Molecules present in liquids and gases have freedom of motion, and by moving from a hot to a cold region, they carry energy with them. The transfer of heat from one region to another, due to such macroscopic motion in a liquid or gas, added to the energy transfer by conduction within the fluid, is called heat transfer by convection. Convection may be free, forced or mixed. Convection heat transfer also occurs in boiling and condensation processes.

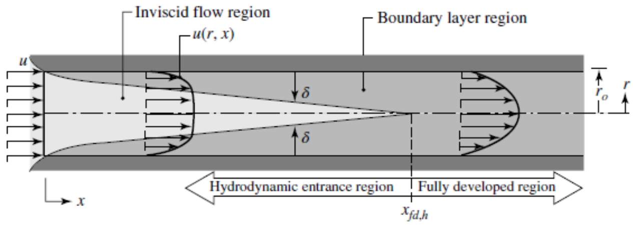


Figure 1.2: Laminar, hydrodynamic boundary layer development in a circular tube

The design of a helical coil tube in tube heat exchanger has been facing problems because of the lack of experimental data available regarding the behavior of the fluid in helical coils and also in case of heat transfer data, which is not the case in Shell & Tube Heat Exchanger. So to the best of our effort, numerical analysis was carried out to determine the heat transfer characteristics for a double-pipe helical heat exchanger by varying the different parameters like different temperatures and diameters of pipe and coil and also to determine the fluid flow pattern in helical coiled heat exchanger. The objective of the project is to obtain a better and more quantitative insight into the heat transfer process that occurs when a fluid flows in a helically coiled tube. The study also covered the different types of fluid flow range extending from laminar flow through transition to turbulent flow. The materials for the study were decided and fluid taken was water and the material for the pipe was taken to be copper for its better conducting properties.

2. Methodology

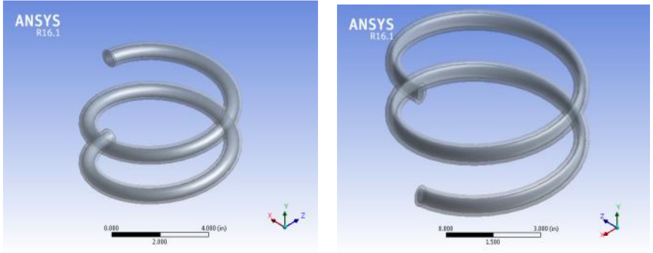
a) Heat Exchangers Design

Many engineering systems, including power plants, climate control, and engine cooling systems typically contain tubular heat exchangers. However, for most engineering problems, it is impractical to model individual fins and tubes of a heat exchanger core. In principle, heat exchanger cores introduce a pressure drop to the primary fluid stream and transfer heat from or to a second fluid (such as a coolant), referred to here as the auxiliary fluid.

In ANSYS Fluent, lumped-parameter models are used to account for the pressure loss and auxiliary fluid heat rejection. ANSYS Fluent provides two heat exchanger models: the macro (ungrouped and grouped) models and the dual cell model. The macro model allows you to choose between two heat transfer models, namely the **simple-effectiveness-model** and the number-of-transfer-units (NTU) model. The models can be used to compute auxiliary fluid inlet temperature for a fixed heat rejection or total heat rejection for a fixed auxiliary fluid inlet temperature. For the **simple-effectiveness-model**, the auxiliary fluid may be single-phase or two-phase. The dual cell model uses the NTU method for heat transfer calculations. This model allows the solution of auxiliary flow on a separate mesh (other than the primary fluid mesh), unlike the macro model, where the auxiliary flow is modeled as 1D flow. The dual cell model also offers more flexibility as far as the shape of the heat exchanger is concerned, and overcomes some of the major limitations present in the macro model.

b) Geometric Characteristics of both the model -

Heat exchanger is built in the ANSYS workbench 16.1 module it has a counter-flow. In this research there were two separate models of helical heat exchanger with circular and elliptical cross section of helical tubes were created.



(a) (b)

Figure 1.3 (a) & (b) solid models of helical heat exchanger with circular and elliptical type of inner tube.

While creating model of circular cross section inner tube helical heat exchanger, firstly a 4 inch line for the height of the helical structure is made with respect plane. A new plane is created in reference with the initial plane (YZ-plane) where a circle of diameter 0.545 inch at a distance of 3 inch from origin. In next sketch, two circles of diameters 0.545 inch and 0.625 inch are made concentric to previous circle. Further sketch of two circles of diameters 0.625 inch and 0.785 inch are made concentric to previous circles. And finally, two circles of diameters 0.785 inch and 0.875 inch are made concentric to previous circles. Similarly, creating model of elliptical cross section inner tube helical heat exchanger, firstly a 4 inch line for the height of the helical structure is made with respect plane. A new plane is created in reference with the initial plane(YZ-plane) where an ellipse of major axis 0.785 inch and minor axis of 0.5125 inch at a distance of 3 inch from origin. In next sketch , another ellipse with major axis 0.545 inch and minor axis 0.2725 inch are made concentric to previous ellipse.

Table 1.1: Geometric properties of circular cross section heat exchanger

Object Name	*outer*	*inner*
State	Meshed	
Material		
Fluid/Solid	Fluid	
Properties		
Volume	1.5483e-004 m³	1.4406e-004 m³
Centroid X	8.3392e-010 m	3.2279e-010 m
Centroid Y	5.0798e-002 m	5.08e-002 m
Centroid Z	3.4264e-010 m	1.4585e-010 m
Statistics		
Nodes	73736	126875
Elements	50976	115840

Table 1.2: Geometric properties of circular cross section heat exchanger

Object Name	*outer*	*inner*
State	Meshed	
Material		
Fluid/Solid	Fluid	
Properties		
Volume	1.2312e-004 m³	7.2081e-005 m³
Centroid X	1.9224e-008 m	5.431e-009 m
Centroid Y	5.08e-002 m	
Centroid Z	-4.9279e-010 m	2.1115e-010 m
Statistics		
Nodes	437760	478400
Elements	367073	440730

After generating Sketch of circular and elliptical cross section inner tube helical heat exchanger are swept along the line made in sketch using the" add frozen" operation to construct the 3D model with different parts. The helical sweep is of 2 turns because the twist specification is defined in number of turns.

Table 1.3: Naming of various parts of the body with state type

Model	Part Name	Physical State Type
Circular cross section inner tube helical heat exchanger	Inner tube	Hot fluid
	Outer tube	Cold fluid
Elliptical cross section inner tube helical heat exchanger	Inner tube	Hot fluid
	Outer tube	Cold fluid

c) Meshing features of models

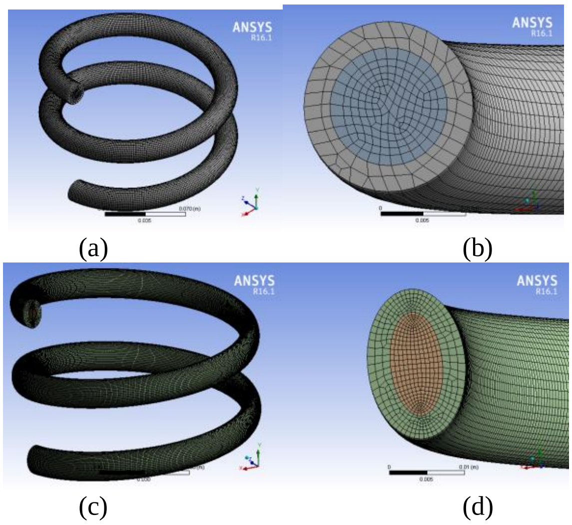
Once the model of both the type of heat exchanger are ready it is later transfer to mesh modular where a relative coarser mesh is generated with physical preference of computational fluid dynamics, Solver Preference to be 'Fluent' and with relevance 100.

Table 1.4: Meshing details of both the models of heat exchanger

Meshing details	
Physics Preference	CFD
Solver Preference	Fluent
Relevance	100
Sizing	
Use Advanced Size Function	On: Curvature
Relevance Center	Fine
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Slow
Span Angle Center	Fine
Curvature Normal Angle	Default (12.0 °)
Min Size	Default (2.6362e-005 m)
Max Face Size	Default (2.6362e-003 m)
Max Size	Default (5.2725e-003 m)
Growth Rate	Default (1.10)
Minimum Edge Length	3.3529e-002 m
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No

This mesh contains mixed cells (Tetra and Hexahedral cells) having both triangular and quadrilateral faces at the boundaries. Care is taken to use structured hexahedral cells as much as possible. It is meant to reduce numerical diffusion as much as possible by structuring the mesh in a well manner, particularly near the wall region. Later on, a fine mesh is generated. For this fine mesh, the edges and regions of high temperature and pressure gradients are finely meshed.

Mesh details	Circular	Elliptical
Nodes	200611	916160
Elements	166816	807803

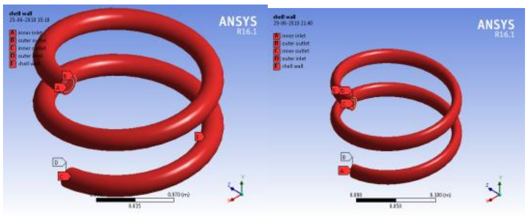


(c) (d)

Figure 1.4 (a), (b) Geometry for Meshing for circular cross section inner tube heat exchanger & (c), (d) for Meshing for elliptical cross section inner tube heat exchanger

d) Named Selection

The different surfaces of the solid are named as per required inlets and outlets for inner and outer fluids. The outer wall is named as insulation surface. Save project again at this point and close the window. Refresh and update project on the workbench. Now open the setup. The ANSYS Fluent Launcher will open in a window.



(a) (b)

Figure 1.5: Name selection of helical heat exchanger with circular and elliptical type of inner tube

e) Solution (fluent setting)

After generating geometry and mesh model is been transfer to ANSYS workbench Fluent. The ANSYS Fluent Launcher will open in a window. Set dimension as 3D, option as Double Precision, processing as Serial type and set OK. Model is imported after checking mesh and its quality is obtained. Now defining the boundary condition with respect to required analysis. Setting the analysis type on General setup is changed to Pressure Based type with velocity formulation to absolute and time to steady state. Gravity is defined as y = -9.81 m/s^2

- **Model**

Model tab Energy is set to ON position. Viscous model is selected as “k-ε model (2 equations). Heat Exchanger model is changed to Dual cell model.

- **Materials**

The create/edit option is clicked to add water-liquid respectively from the fluent database with respective properties-

density (kg/m3	998.2
Cp(specific Heat) (j/kg-k)	4182
Thermal Conductivity (w/m-k)	0.6
Viscosity (kg/m-s)	0.001003

- **Cell zone conditions**

The parts are assigned as hot and cold water as per fluid parts refer to table 3.3.

- **Boundary Conditions**

Boundary conditions are used according to the need of the model. The inlet and outlet conditions are defined as velocity inlet and pressure outlet. As this is a counter-flow with two tubes so there are two inlets and two outlets. The details about all boundary conditions can be seen in the table as given below.

Table 1.5: Boundary Conditions

		Boundary Condition Type	Velocity Magnitude	Turbulent Kinetic Energy	Turbulent dissipation Rate	temperature
Circular cross section heat exchanger	Inner inlet	Velocity inlet	0.9942 m/s	0.01 m^2/s^2	0.1 m^2/s^3	348 K
	Inner outlet	Pressure outlet	-	-	-	-
	Outer inlet	Velocity inlet	1.8842 m/s	0.01 m^2/s^2	0.1 m^2/s^3	283 K
	Outer outlet	Pressure outlet	-	-	-	-
Elliptical cross section heat exchanger	Inner inlet	Velocity inlet	0.9942 m/s	0.01 m^2/s^2	0.1 m^2/s^3	348 K
	Inner outlet	Pressure outlet	-	-	-	-
	Outer inlet	Velocity inlet	1.8842 m/s	0.01 m^2/s^2	0.1 m^2/s^3	283 K
	Outer outlet	Pressure outlet	-	-	-	-

- **Solution Control and Initialization**

Under relaxation factors the parameters are

Property	Values
Pressure	0.3 Pascal
Density	1 kg/m^3
Body forces	1 kg/m^2s^2
Momentum	0.7 kg-m/s
Turbulent kinetic energy	0.8 m^2/s^2

Then the solution initialization method is set to Standard Initialization whereas the reference frame is set to Relative cell zone. The number of iteration is set to 50 and the solution is calculated and various contours, vectors and plots are obtained.

3. Results and Discussion

Since the fluid flow through a circular cross section is taken as standard for our comparable analysis of the heat transfer efficiency of an helical cross flow heat exchanger for a circular and elliptical cross sections. A circular cross-sectional helical heat exchanger model with properties defined was generated in a finite element software i.e. Ansys in this case. This model was subjected to simulation of the fluid flow through it and all the final and intermediate parameters were recorded for a given input parameters.

In this our comparable analysis of the heat transfer efficiency of an helical cross flow heat exchanger for a circular and elliptical cross sections we are faced with 2 options while choosing the cross sections of elliptical cross section

1) The major axis parallel helix axis
2) The major axis of ellipse perpendicular to the helical axis

But since we are concerned with the maximisation of the heat transfer efficiency we have to look into the factors responsible to increase the heat transfer between liquid solid interface.

These factors are
1) The viscosity of the fluid
2) The thermal heat transfer coefficient of the wall material
3) The type of flow – smooth, turbulent

Table 1.5 (o) Average of Surface Vertex Values Figure 1.5 (a) Contours of Velocity Magnitude (circular)

Velocity Magnitude	**(m/s)**
inner_inlet	0.82376571
inner_outlet	0.85085908
interior-inner	0.85421907
interior-outer	0.62163555
outer_inlet	0.61598844
outer_outlet	0.6191489
Net	**0.76869437**

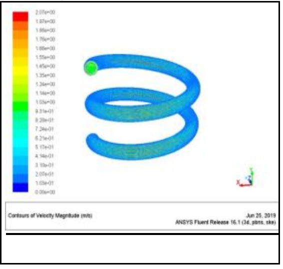


Table 1.6 (o): Average of Surface Vertex Values Figure 1.6 (a) Contours of Velocity Magnitude(elliptical)

Velocity Magnitude	(m/s)
inner_inlet	0.83264249
inner_outlet	1.32775
interior-inner	0.75711277
interior-outer	1.0391068
outer_inlet	1.2561333
outer_outlet	1.1239776
Net	0.89220896

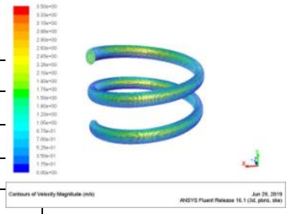


Table 1.6 (o): Average of Surface Vertex Values Figure 1.6 (a) Contours of Velocity Magnitude(elliptical)

Table 1.7 (j) Average of Surface Vertex Values Figure 1.7(b) Contours of Turbulent Kinetic Energy (k) (circular)

Turbulent Kinetic Energy (k)	(m^2/s^3)
inner_inlet	0.0037066261
inner_outlet	0.0091363853
interior-inner	0.0084449397
interior-outer	0.042419434
outer_inlet	0.013657071
outer_outlet	0.045572978
Net	0.020916238

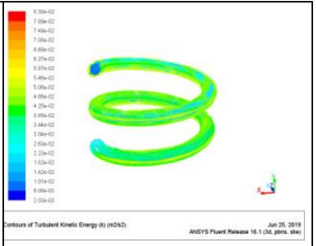


Table 1.8 (i) Average of Surface Vertex Values Figure 1.8 (b) Contours of Turbulent Kinetic Energy (elliptical)

Turbulent Kinetic Energy (k)	(m^2/s^3)
inner_inlet	0.0037066261
inner_outlet	0.26097536
interior-inner	0.084565601
interior-outer	0.17486545
outer_inlet	0.013687059
outer_outlet	0.030706275
Net	0.12763728

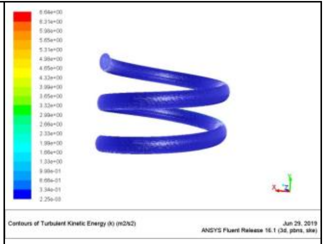


Table 1.9 (m): Average of Surface Vertex Values   Figure 1.9 (j) Contours of Cell Reynolds Number (circular)

Cell Reynolds Number	
inner_inlet	118.63843
inner_outlet	43.637718
interior-inner	48.790539
interior-outer	83.351705
outer_inlet	132.90443
outer_outlet	96.09601
Net	**61.582725**

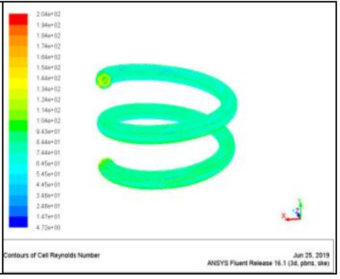


Table 1.10: Average of Surface Vertex Values Figure 1.10 Contours of Cell Reynolds Number (elliptical)

Cell Reynolds Number	
inner_inlet	62.454109
inner_outlet	30.065553
interior-inner	22.876303
interior-outer	59.105101
outer_inlet	152.57212
outer_outlet	65.118109
Net	**40.242586**

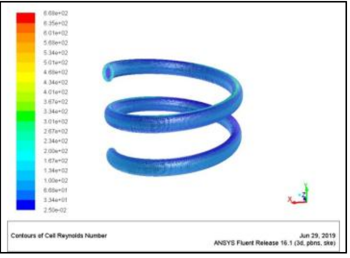


Table 1.11: Average of Surface Vertex Values Figure 1.11 Contours of Dynamic Pressure (circular)

Dynamic Pressure	(pascal)
inner_inlet	491.95928
inner_outlet	511.60216
interior-inner	512.63933
interior-outer	1797.0347
outer_inlet	1764.8928
outer_outlet	1791.0209
Net	984.70791

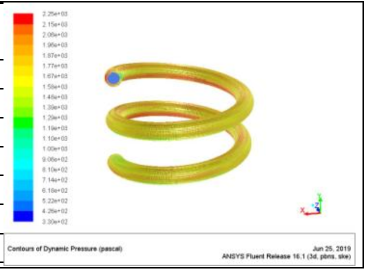
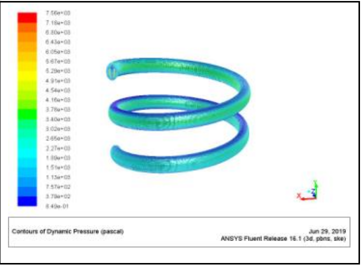


Table 1.12: Average of Surface Vertex Values   Figure 1.12 Contours of Dynamic Pressure (elliptical)

Dynamic Pressure	(pascal)
inner_inlet	492.18815
inner_outlet	2107.65
interior-inner	487.5537
interior-outer	1452.2942
outer_inlet	1757.1749
outer_outlet	1446.6587
Net	949.25868



4. Conclusion

The numerical study using (ANSYS Fluent 16.0) of the heat transfer through double pipe helical heat exchanger for counter flow using circular and elliptical profile were compared.

5. Comparison of the Two Cases

For comparable analysis of the heat transfer efficiency of an helical cross flow heat exchanger for a circular and elliptical cross sections we should compare the

1) Final temperature of the cold fluid- The higher it will be, more is the transfer efficiency
2) The final temperature of the heat transfer
3) The average heat transfer rate per unit area in both case.

6. Analysis

For finding the reasons behind the improved performance we must go into factors effecting the heat transfer in the heat exchangers which are already listed before. Provided the length of the helical exchanger is same along with the fluid properties and the parameter changed in both case was the distance from the helical centre the fluid is flowing which in turn affects the curve of fluid flowing.

References

[1] "Performance of continuous helical baffled heat exchanger with varying elliptical tube layouts" by Tingting Dua, Qi Chen, Wenjing Dua, Lin Cheng, International Journal of Heat and Mass Transfer 133 (2019) 1165–1175, 2019.
[2] "Study of intensification of the heat transfer in helically coiled tube heat exchangers via coiled wire inserts" by Ehsan Gholamalizadeha, Ebrahim Hosseinib, Mohammadreza Babaei Jamnanic, Ali Amirid, Ali Dehghan saeee, Ashkan Alimoradif, International Journal of Thermal Sciences 141 (2019) 72–83, 2019.
[3] "Experimental and numerical study on heat transfer and flow characteristics in the shell side of helically coiled trilobal tube heat exchanger" by Guanghui Wang, Dingbiao Wang*, Xu Peng, Luole Han, Sa Xiang, Fei Ma, Applied Thermal Engineering, 2018.
[4] "Experimental and Numerical Investigations on the Heat Transfer and Flow Characteristics of a Helical Coil Heat Exchanger" by A. Sheeba , C.M. Abhijith , M. Jose Prakash, International Journal of Refrigeration, 2018.
[5] "CFD study of heat transfer and pressure drop for oscillating flow in helical rectangular channel heat exchanger" by Changzhao Pana, Tong Zhanga, Junjie Wanga, Yuan Zhoua, International Journal of Thermal Sciences 129 (2018) 106–114, 2018.
[6] "Effect of Helical Diameter on the Performance of Shell and Helical Tube Heat Exchanger: An Experimental Approach" by M. Rahimi, M.J. Hosseini, M. Gorzin, Sustainable Cities and Society (2018).
[7] "Experimental studies of heat transfer of air in a double-pipe helical heat exchanger" by Davood Majidi, Hashem Alighardashi, Fatola Farhadi, Applied Thermal Engineering 133 (2018) 276–282, 2018.
[8] "Investigation of exergy efficiency in shell and helically coiled tube heat exchangers" by Ashkan Alimoradi, Case Studies in Thermal Engineering 10 (2017) 1–8, 2017.
[9] "Study of thermal effectiveness and its relation with NTU in shell and helically coiled tube heat exchangers" by Ashkan Alimoradi, Case Studies in Thermal Engineering 9 (2017) 100–107, 2017.
[10] "Comparison and Analysis of Heat Transfer Enhancement for Wastewater Heat Exchanger in Wastewater Source Heat Pump System" by Yimeng Wanga, Yapeng Rena, Yaxiu Gub, and Qingke Menga, Procedia Engineering 205 (2017) 2736–2743, 2017.
[11] "2D Axisymmetric Model Research of Helical Heat Exchanger inside Pile Foundations" by Procedia Engineering 205 (2017) 3503–3510, 2017.

[12] "Parametric investigation of helical ground heat exchangers for heatpump applications" by Babak Dehghan, Altug Sisman, Murat Aydin, Energy and Buildings 127 (2016) 999–1007, 2016.

[13] "Experimental Investigation of the Heat Transfer Characteristics of a Helical Coil Heat Exchanger for a Seawater-Source Heat Pump" by Wandong Zheng, Ph.D.1; Tianzhen Ye2; Shijun You3; Huan Zhang4; and Xuejing Zheng5, J. Energy Eng., 2016, 142(1): 04015013, 2016.

[14] "Mathematical Model for Predicting the Heat Transfer Characteristics of a Helical-Coiled, Crimped, Spiral, Finned-Tube Heat Exchanger" by Roumsak Boonsria & Somchai Wongwisesa, Heat Transfer Engineering, DOI: 10.1080/01457632.2015.987608, 2015.

[15] "Calculation code for helically coiled heat recovery boilers" by Alberto Sogni a,*, Paolo Chiesab, Energy Procedia 45 (2014) 492 – 501, 2014.

[16] "Experimental and CFD study of a single phase cone-shaped helical coiled heat exchanger: an empirical correlation" By Daniel Flórez-Orrego, ECOS June 26-29, 2012.

[17] Helically Coiled Heat Exchangers by J.S.Jayakumar. "Numerical And Experimental Studies of a Double pipe Helical Heat Exchanger" by Timothy John Rennie, Dept. of Bio-resource Engg. McGill University, Montreal August 2004.

[18] "Experimental and CFD estimation of heat transfer in helically coiled heat exchangers" by J.S. Jayakumar, S.M. Mahajani, J.C. Mandal, P.K. Vijayan, and Rohidas Bhoi, 2008, Chemical Engg Research and Design 221-232.

[19] "Heat Transfer Optimization of Shell-and-Tube Heat Exchanger through CFD Studies" by Usman Ur Rehman, 2011, Chalmers University of Technology.

[20] "Structural and Thermal Analysis of Heat Exchanger with Tubes of Elliptical Shape" by Nawras H. Mostafa Qusay R. Al-Hagag, IASJ, 2012,Vol-8 Issue-3.

[21] "Numerical analysis of forced convection heat transfer through helical channels" by Dr. K. E. Reby Roy, IJEST, July-2012 vol-4.

[22] "Minton P.E., Designing Spiral Tube Heat Exchangers", Chemical Engineering, May 1970, p. 145.

[23] "Noble, M.A., Kamlani, J.S., and McKetta, J.J., Heat Transfer in Spiral Coils, Petroleum Engineer, April 1952, p. 723.

[24] "Heat Transfer Analysis of Helical Coil Heat Exchanger with Circular and Square Coiled Pattern" by Ashok B. Korane, P.S. Purandare, K.V. Mali, IJESR, June 2012, vol-2, issue-6.