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International
Journal
Of Modern Engineering Research (IJMER)

Three Dimensional Computational Fluid Dynamic Performances Analysis of Helical Coil and Straight Tube Heat Exchanger

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ABSTRACT *: The purpose of this study is to simulate experimental study with computational fluid dynamics study for validation the Geometrical model is developed from literature for simulation. Geometrical model creation and meshing is done by ANSYS Workbench 12.1. That's why it is important to design the heat exchanger in such a way that it can give best performance so that optimum effectiveness can be achieved. Conventionally the models of large size heat exchanger are tested and analysed in the laboratory to determine their performance characteristics. This is a time consuming and costly process. High computing facility along with these of numerical techniques can give the solution to any fluid flow problem in a lesser time. Fluid flow and heat transfer are simulated and get result of effectiveness of heat exchanger when hot water mass flow rate is kept constant and cold water mass flow rate changer. where Input parameter are inlet velocity, temperature, rate of fluid flow for hot fluid flow in (LPH) and rate of fluid flow for cold fluid in (LPH) Measured parameter are hot fluid outlet temperature, cold fluid out let temperature, heat taken by cold fluid, heat given by hot fluid, change in temperature in hot fluid as well cold fluid for parallel flow, counter flow arrangement of Helical coil and Straight tube heat exchangers. Model validation is carried out by comparing the effectiveness from experimental result from the literature.*

KEY WORDS: *Helical coil heat exchanger, Straight tube heat exchanger, computational fluid dynamics, Effectiveness, parallel Flow, counter flow*

I. INTRODUCTION

Heat exchangers are used in a wide variety of applications including power plants, nuclear reactors, refrigeration and air-conditioning systems, automotive industries, heat recovery systems, chemical processing, and food industries .Besides the performance of the heat exchanger being improved, the heat transfer enhancement enables the size of the heat exchanger to be considerably decreased. In general, the enhancement techniques can be divided into two groups: active and passive techniques. The active techniques require external forces like fluid vibration, electric field, and surface vibration. The passive techniques require special surface geometries or fluid additives like various tube inserts. Both techniques have been widely used to improve heat transfer performance of heat exchangers. Due to their compact structure and high heat transfer coefficient, helically coiled tubes have been introduced as one of the passive heat transfer enhancement techniques and are widely used in various industrial applications. Several studies have indicated that helically coiled tubes are superior to straight tubes when employed in heat transfer applications .The centrifugal force due to the curvature of the tube results in the secondary flow development which enhances the heat transfer rate. This phenomenon can be improve in helical coil heat exchanger as compeered to straight tube in parallel and counter flow arrangement Thermal performance ,overall heat transfer and effectiveness of a shell and helically coiled tube heat exchanger have been investigated by N. D. Shirgire Going through the existing literature, The purpose of this study is to use computational fluid dynamics (CFD) software to simulate effectiveness and overall heat transfer in a straight tube & helical tube heat exchanger and validate the simulation with an actual experimental results from the Literature. ANSYS Fluent 12.1 solvers and laminar models are used to try to determine the most accurate CFD method for predicting heat transfer in this type of compact straight tube & helical tube heat exchanger. For parallel and counter flows arrangement.

II. LITERATURE SURVEY

The following research papers are studied in detail and the abstract of the work is presented here:

Timothy J. Rennie, Vijaya G.S. Raghavan [1] Have done An experimental study of a double-pipe helical heat exchanger. Two heat exchanger sizes and both parallel flow and counter flow configurations were tested. Flow rates in the inner tube and in the annulus were varied and temperature data recorded. Overall heat transfer coefficients were calculated and heat transfer coefficients in the inner tube and the annulus were determined using Wilson plots. Nusselt numbers were calculated for the inner tube and the annulus. The inner Nusselt number was compared to the literature values. Though the boundary conditions were different, a reasonable comparison was found. The Nusselt number in the annulus was compared to the numerical data. D. G. Prabhanjan, G. S. V. Ragbavan and T. J. Kennic [2] Have done experimental study to determine the relative advantage of using a helically coiled heat exchanger versus a straight tube heat exchanger for heating liquids. The particular difference in this study compared to other similar studies was the boundary conditions for the helical coil. Most studies focus on constant wall temperature or constant heat flux, whereas in this study it was a fluid-to-fluid heat exchanger. All tests were performed in the transitional and turbulent regimes. H. Shokouhmand, M.R. Salimpour, M.A. Akhavan-Behabadi [3] Have done an experimental investigation of the shell and helically coiled tube heat exchangers. Three heat exchangers with different coil pitches and curvature ratios were tested for both parallel-flow and counter-flow configurations. All the required parameters like inlet and outlet temperatures of tube-side and shell-side fluids, flow rate of fluids, etc. were measured using appropriate instruments. Overall heat transfer coefficients of the heat exchangers were calculated using Wilson plots. The inner Nusselt numbers were compared to the values existed in open literature. Nasser Ghorbani, Hessam Taherian, Mofid Gorji, Hessam Mirgolbabaei [4], Have done an experimental investigation of the mixed convection heat transfer in a coil-in-shell heat exchanger is reported for various Reynolds and Rayleigh numbers, various tube-to-coil diameter ratios and dimensionless coil pitch. The purpose of this article is to check the influence of the tube diameter, coil pitch, shell-side and tube-side mass flow rate over the performance coefficient and modified effectiveness of vertical helical coiled tube heat exchangers. The calculations have been performed for the steady-state and the experiments were conducted for both laminar and turbulent flow inside coil. It was found that the mass flow rate of tube-side to shell-side ratio was effective on the axial temperature profiles of heat exchanger -Nian Chen, Ji-Tian Han, Tien-Chien Jen N. D. Shirgire Amit Thakur, Sanjay Singh ,et al.,[5] current work the fluid to fluid heat exchange is taken into consideration. Most of the investigations on heat transfer coefficients are for constant wall temperature or constant heat flux. The effectiveness, overall heat transfer coefficient, effect of cold water flow rate on effectiveness of heat exchanger when hot water mass flow rate is kept constant and effect of hot water flow rate on effectiveness when cold water flow rate kept constant studied and compared for parallel flow, counter flow arrangement of Helical coil and Straight tube heat exchangers. All readings were taken at steady state condition of heat exchanger.The result shows that the heat transfer coefficient is affected by the geometry of the heat exchanger. Helical coil heat exchanger are superior in all aspect studied

III. COMPUTATIONAL DOMAIN AND BOUNDARY CONDITIONS

1. Construction of a geometrical model

First we have to make a Drawing of Geometrical Model, whose dimension is taken from literature**.**

Table 1: Dimension of Model for helical tube heat exchanger

Geometrical Parameter from literature		
Copper Tube length	l	10.5 m
Tube Inner Diameter	d	0.65 cm
Tube Thickness	t	1 mm
Shell length	L	50 cm
Shell inner Diameter	Ds	13 cm
Shell outer Diameter	ds	15.5 cm
Pitch	P	1.4 cm
PCD	D	9.5 cm
No. of Turns	T	37

From the Table of Dimension of Model, Develop a 3 dimensional geometrical model of helical coil heat exchanger for computational fluid dynamics (CFD) Simulation in ANSYS Workbench. First define analysis type 3D then draw the geometry. Draw a sketch of tube. Then extrude it with extrude command. This extrude command help to draw a 3 Dimensional model. It consist inlet, wall and outlet.

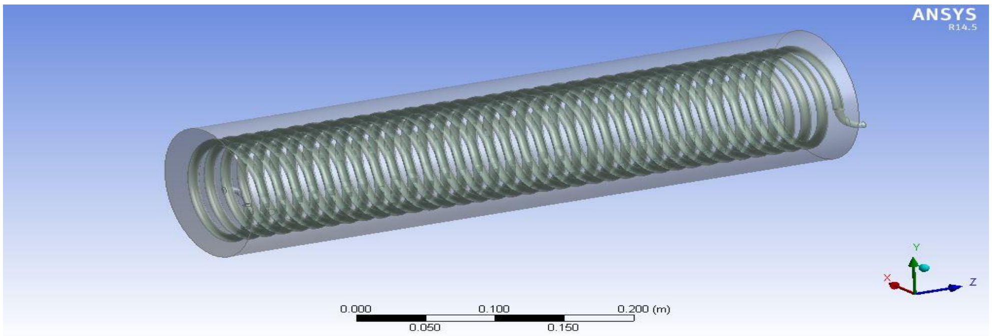


Fig 1: The main computational domain and geometric parameters of the heat exchanger model studied

Table 2: Dimension of Model for straight tube heat exchanger

Geometrical Parameter from literature		
Copper Tube length	l	10.5 m
Tube Inner Diameter	d	0.65 cm
Tube Thickness	t	1 mm
Shell length	L	50 cm
Shell inner Diameter	Ds	13 cm
Shell outer Diameter	ds	15.5 cm
Pitch	P	1.4 cm
PCD	D	9.5 cm
No. of Turns	T	37

From the Table Straight tube heat exchanger consists of 6.5 mm inner diameter copper tube and length equivalent to the stretched length of the helical coil (10.5 m). This tube is divided into 21 equivalent parts of length 50 cm.of Dimension of Model, Develop a 3 dimensional geometrical model of Straight tube heat exchanger for computational fluid dynamics (CFD) Simulation in ANSYS Workbench. First define analysis type 3D then draw the geometry. Draw a sketch of Straight tube heat exchanger. Then extrude it with extrude command. This extrude command help to draw a 3 Dimensional model. It consist inlet, wall and outlet.

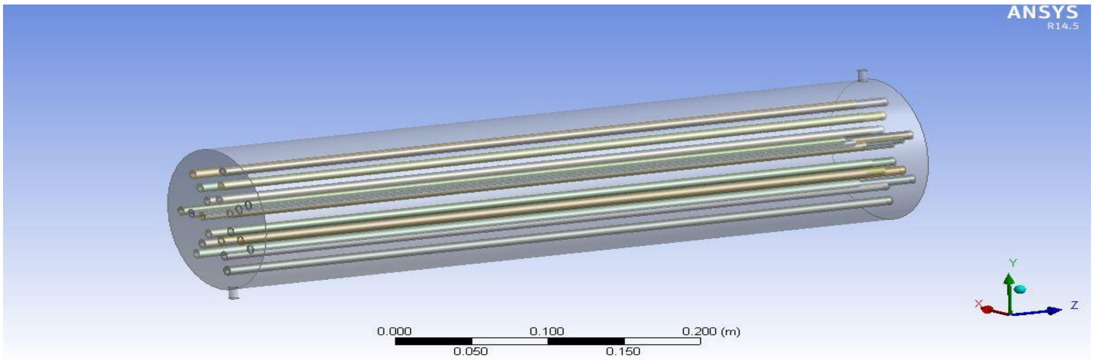


Fig 2: The main computational domain and geometric parameters of the heat exchanger model studied

2. Materials used:-

Water (fluid)

Copper (solid)

Table 3: Materials Properties

Properties	**Water**	**Copper**
Density (ρ)	1000 Kg/m^3	8978 Kg/m^3
Thermal Conductivity (k)	0.563W/m-k	387.6 W/m-k
Specific Heat ($C_{P)}$)	4.19 J/Kg-k	381 J/Kg-k

3. Boundary Condition:-

Table 4: Boundary Condition

Boundary Condition [N. D. Shirgire ,et al]		
Hot fluid velocity for parallel flow as well as counter flow in both case	Inlet Velocity	V = 0.419 m/s
cold fluid velocity for parallel flow as well as counter flow in both case	Inlet Velocity	0.251 m/s 0.419m/s 0.587m/s 0.712m/s
hot fluid mass flow rate (LPH)	Inlet	50 LPH
cold fluid mass flow rate (LPH)	Inlet	30,50,70,85 LPH
Fluid	Type of fluid flow in shell & tube heat exchanger	water

3.1 Velocity inlet Boundary Condition: Velocity inlet boundary condition has been used at plane of the helical coil heat exchanger and straight tube heat exchanger geometry. A uniform velocity profile for hot fluid flow and varying velocity profile for cold fluid flow is prescribed at inlet plane.

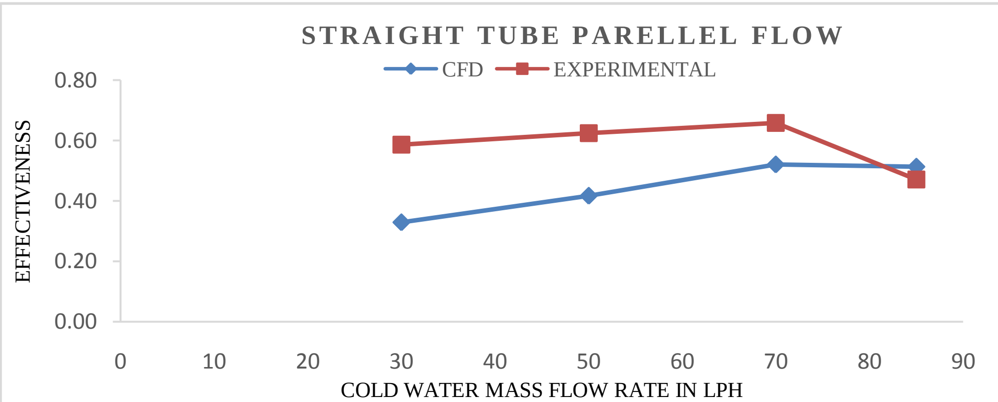
3.2Temperature inlet Boundary Condition: Temperature inlet boundary condition has been used at plane of helical coil heat exchanger and straight tube heat exchanger geometry. A temperature profile (T_{in}) is prescribed at inlet plane.

3.3 Hot fluid flow Boundary Condition: heat exchanger inlet fluid flow boundary condition has been used at plane of helical coil heat exchanger and straight tube heat exchanger geometry A flow profile (M_h) is prescribed at inlet plane.

3.4Cold fluid flow Boundary Condition: heat exchanger inlet fluid flow boundary condition has been used at plane of helical coil heat exchanger and straight tube heat exchanger geometry A flow profile (M_c) is prescribed at inlet plane.

IV. RESULTS AND DISCUSSION

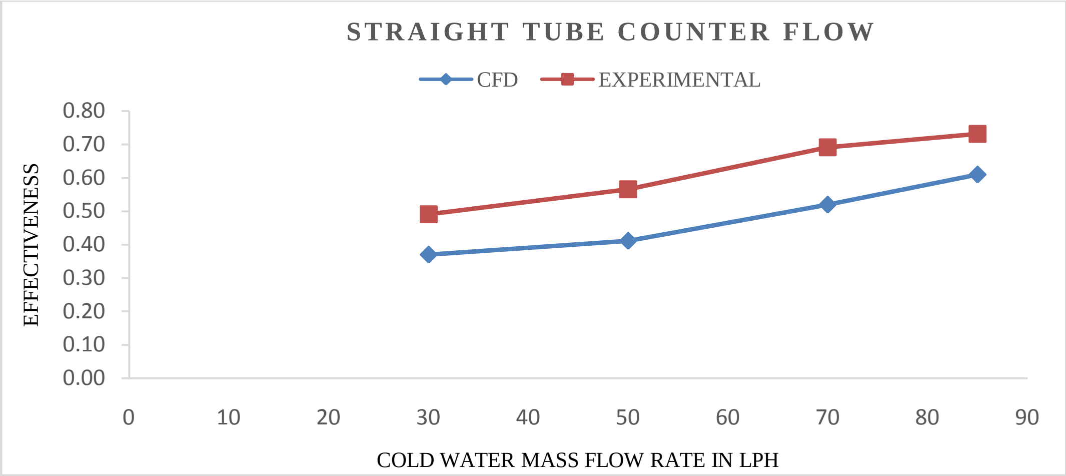
The graph shows the comparison between the effectiveness of straight tube and helical tube for different arrangement of parallel, counter flow for experimental and computational fluid dynamics (CFD) study when hot fluid flow rate is constant i.e 50 LPH with a velocity of 0.419 m/s and cold fluid flow rate changes i.e 30,50,70,85 LPH with respect to velocity of 0.251, 0.419, 0.587, 0.712 m/s the Following data taken from experimental results from literature compared with computational fluid dynamics (CFD) Simulation Result



Graph 1: STRAIGHT TUBE PARELLEL FLOW

In this arrangement the graph plotted between effectiveness vs. cold water mass flow rate in case of straight tube parallel flow condition which shows the comparison of effectiveness between computational fluid dynamics (CFD) and experimental study

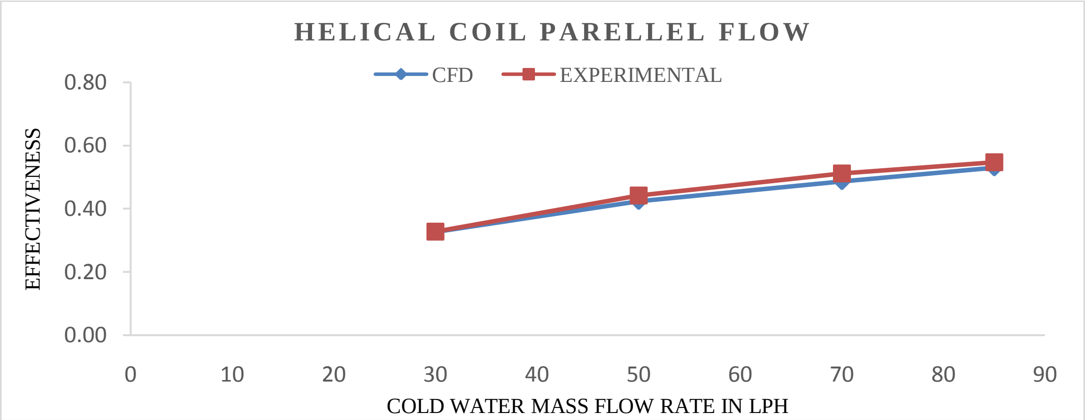
1. In both the case of experimental study as well computational fluid dynamics (CFD) as the mass flow rate of cold water increase the effectiveness of heat exchanger also increase and when mass flow rate increased after 70lph the effectiveness goes on decreased in both the cases
2. As we seen in graph the experimental study is having higher effectiveness as compared to computational fluid dynamics (CFD) due to fluid flow in pipe with constant velocity so due to the boundary condition



Graph 2: STRAIGHT TUBE COUNTER FLOW

In this arrangement the graph plotted between effectiveness vs. cold water mass flow rate in case of straight tube counter flow condition which shows that the comparison of effectiveness between computational fluid dynamics (CFD) and experimental study

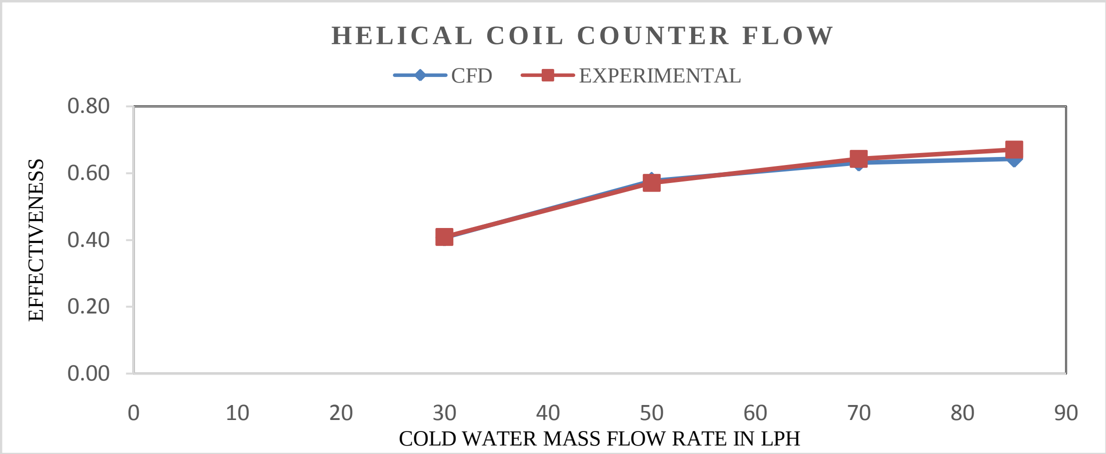
1. In both the case of experimental study as well computational fluid dynamics (CFD) the mass flow rate of cold water increase the effectiveness increase
2. As we seen in graph the experimental study is having higher effectiveness as compared to computational fluid dynamics (CFD) due to constant fluid flow or the boundary condition



Graph 3: HELICAL COIL PARELLEL FLOW

In this arrangement the graph plotted between effectiveness vs. cold water mass flow rate in case of helical coil tube parallel flow condition which shows that the comparison of effectiveness between computational fluid dynamics (CFD) and experimental study

1. In both the case of experimental study as well computational fluid dynamics (CFD) the mass flow rate of cold water increase the effectiveness increase
2. At the flow rate of 30lph both having same effectiveness as the flow increased up to 85lph the effectiveness is slightly changes in both the case due to flow pattern



Graph 4: HELICAL COIL COUNTER FLOW

In this arrangement the graph plotted between effectiveness vs. cold water mass flow rate in case of helical coil tube counter flow condition which shows that the comparison of effectiveness between computational fluid dynamics (CFD) and experimental study

1. In both the case of experimental study as well computational fluid dynamics (CFD) the mass flow rate of cold water increase the effectiveness increase
2. At the flow rate of 30lph both having same effectiveness up to the flow rate 70lph as the flow increased above 70lph the effectiveness is slightly changes in both the case due to flow pattern
3. The maximum effectiveness is achieved in the flow rate of 85lph in both the case as compared to all the arrangement discussed above

V. CONCLUSION

1) The effectiveness of heat exchanger greatly affected by hot water mass flow rate and cold water flow rate. Increase in cold water mass flow rate for constant hot water mass flow rate resulted in increase in effectiveness. For both helical coil and straight tube heat exchangers with parallel and counter flow configuration this result obtained
2) Helical coil counter flow is most effective in all these conditions and straight tube parallel flow heat exchanger is least effective.
3) Helical coil counter flow heat exchanger's effectiveness is 22-24 % higher than straight tube parallel flow heat exchanger, 5-7% than straight tube counter flow, 14-17% than helical coil parallel flow heat exchanger under same operating conditions.
4) Straight tube counter flow heat exchanger's effectiveness is 7-10% higher than helical coil parallel flow heat exchanger.

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