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Parametric Optimization and Analysis for the Effect of the Helical Coil Pitch On the Heat Transfer Characteristics of the Helical Coil Heat Exchanger

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Abstract
Helical coil heat exchangers are more efficient to enhance the heat and mass transfer as compared to straight tube type heat exchangers. For any types of heat exchanger, the configuration is very important factor to enhance the heat and mass transfer. This paper deals with the helical coil pitch analysis of helical coil heat exchanger with specific data. In this paper, also comparison the thermal characteristics i.e. heat transfer rate and inside heat transfer coefficient in existing experiment and simulation with CFD software. In this paper, the effect on heat transfer in helical coil heat exchanger due to only pitch, i.e. pitch is variable geometry.
***Keywords**:* Helical coil Heat exchanger, Helical Pitch Coil, solidworks 2009, CFD or computational fluid dynamics, ANSYS CFX 12.1.

I. Introduction

The several studies have indicated that helical 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.

The first attempt has been made by Dean [1, 2] to describe mathematically the flow in a coiled tube. A first approximation of the steady motion of incompressible fluid flowing through a coiled pipe with a circular cross-section is considered in his analysis. It was observed that the reduction in the rate of flow due to curvature depends on a single variable, K, which is equal to 2(Re) 2r/R, for low velocities and small r/R ratio.

Helical coils are known to have better heat and mass transfer compared to straight tubes, the reason for that is the formation of a secondary flow superimposed on the primary flow, known as the Dean Vortex. The Dean Vortex was first observed by Eustice; then numerous studies have been reported on the flow fields that arise in curved pipes (Dean, White, Hawthorne, Horlock, Barua, Austin and Seader).

The first attempt to mathematically describe the flow in a coiled tube was made by Dean. He found that the secondary flow induced in curved pipes (Dean Vortex) is a function of Reynolds Number and the curvature ratio.

The effect of pitch on heat transfer and pressure drop was studied by Austin and Soliman [4] for the case of uniform wall heat flux. The results showed significant pitch effects on both the friction factor and the Nusselt Number at low Reynolds Numbers, though these effects weakened as the Reynolds number increased. The authors suggested that these pitch effects were due to free convection, and thus decrease as the forced convection became more dominant at higher Reynolds Numbers. The effect of the pitch on the Nusselt Number in the laminar flow of helicoidal pipes were also investigated by Yang et al.[5].

II. Helical coil geometry and parameters

The geometry of the helical tube or coil of Experimental Setup is shown in Fig.1; The bottom radius of curvature is denoted (R), the pipe diameter (a), the helical pitch as (P), the straight height (h) and For a straight helical coil the height (h) will be equal to the height of the coil (I) will change in accordance to that angle, while keeping (h) constant.

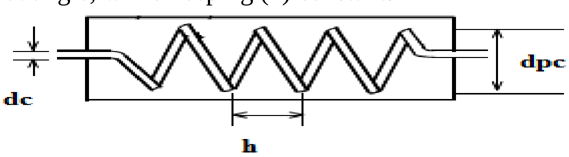

Fig. 1 Geometry of Helical Coil

The present analysis considers the following dimensional and operating parameters:

S. No.	Dimensional Parameters	Dimension
1	Inside Diameter	10 mm
2	Outside Diameter	12.7 mm
3	Pitch Circle Diameter	300 mm
4	Tube Pitch	30 mm

III. Calculation for existing helical coil pitch (30 mm) for experimental setup

3.1 Governing equation for heat transfer rate and inside heat transfer coefficient (h_i):

$Q = m \times C_p \times \Delta T$

Where, Q = heat transfer rate, KW

m = mass flow rate, Kg/s

C_p = specific heat of coolant, KJ/Kg.K

ΔT = Temperature Difference between inlet and outlet temp. of coolant, K and $h_i = Q/ (A\times \{Tavg. \text{ of wall} - Tmean\})$

Q = heat transfer rate, KW

A = area of the coil, m^2

Tavg. of wall = average of wall temperature, K

Tmean = mean temperature of fluid, K

Velocity (m/s)	Heat Transfer from EXPERIMENT(KW)	h_i from EXPERIMENT (KW/m^2 K)
0.2	-0.0003524	0.33831
0.21	-0.0003593	0.31675
0.22	-0.0003557	0.29241
0.23	-0.0003535	0.26227
0.24	-0.0003562	0.24925
0.25	-0.0003512	0.22704

Table: 1. Q and h_i for existing pitch

IV. Simulation of helical coil of heat exchanger

4.1 Modelling of helical coil for existing pitch (30 mm)

Geometries for the heat exchangers were created in solidworks 2009 with 3D Modelling as shown in fig.2 below and then it saves as IGES Format. It is then imported in ANSYS WORKBENCH Meshing Model for mesh generation as shown in fig.3 below. After generating mesh for heat exchanger, the meshed models are then exported as mesh files to CFX-PRE.

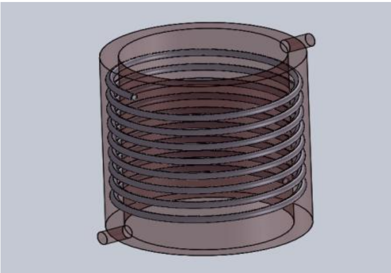

Fig.2 Existing Pitch

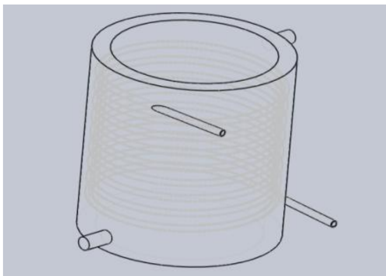

Fig.3 3D Cavity model of Helical Coil Heat Exchanger

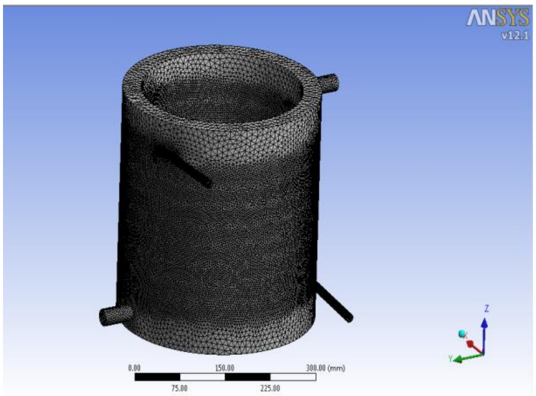

Fig.4 Meshed Geometry

4.2 CFD calculations for existing helical coil pitch

Basic equation for heat transfer rate and inside heat transfer coefficient:

Heat transfer rate, $Q = m \times C_p \times \Delta T$ and Inside heat transfer coefficient, $hi = Q/ (A\times \{Tavg. \text{ of wall} - Tmean\})$

Velocity (m/s)	Heat Transfer from FEM (KW)	h_i from FEM (KW/m^2 K)
0.2	-0.0003614	0.35130
0.21	-0.0003664	0.32583
0.22	-0.0003596	0.29688
0.23	-0.0003670	0.27574
0.24	-0.0003682	0.26029
0.25	-0.0003692	0.24193

Table: 2. Heat transfer rate & inside heat transfer coefficient for existing pitch

V. Optimization of helical coil heat exchanger

The outputs from the system must be obtained for a range of design variables in order to select the optimum design. The optimization of the system may involve minimization of parameters such as in this study, the only one variable is helical coil pitch. Whatever the criterion for optimization, it is essential to change the variables over the design domain, determined by physical limitations and constraints, and to study the system behavior.

5.1 Modelling of helical coil for helical coil pitch (20 mm)

The modelling is done for pitch changed helical coil on the Solid works 2009 version.

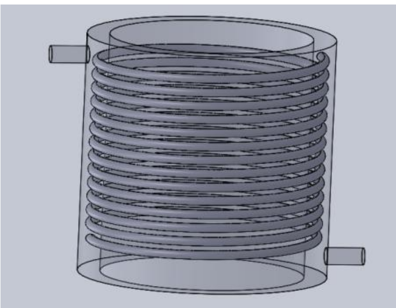

Fig.5 Pitch Changed Helical Coil Heat Exchanger (Pitch 20 mm)

5.2 CFD Simulation of Helical Coil Heat Exchanger with pitch changed:

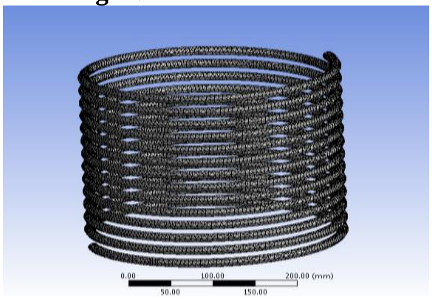

Fig.6 Pitch Changed Meshed Model

Many researchers have applied different Heat transfer models for the analysis of helical coil heat exchanger. In the present work, Heat transfer model was used to consider the heat transfer effect on Helical Coil Heat Exchanger due to Pitch changed of helical coil.

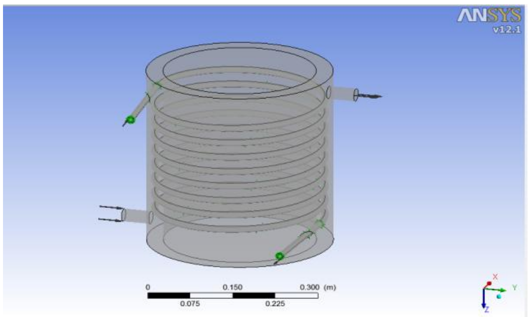

Fig.7 Helical Coil Heat Exchanger in ANSYS CFX PRE

Define all three Domains for pitch changed coil:-

Domain 3:- Outer Cavity
Domain Type: - Stationary Domain (Fluid)
Fluid: - H_2 gas
Heat Transfer Model: - Total Energy

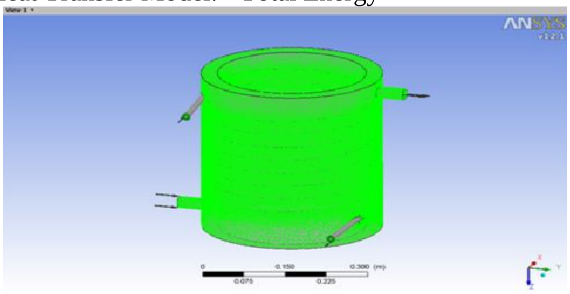

Fig.8 Domain 3

Domain 2:- Pipe
Domain Type: - Stationary Domain (Solid)
Material: - Steel
Heat Transfer Model: - Total Energy

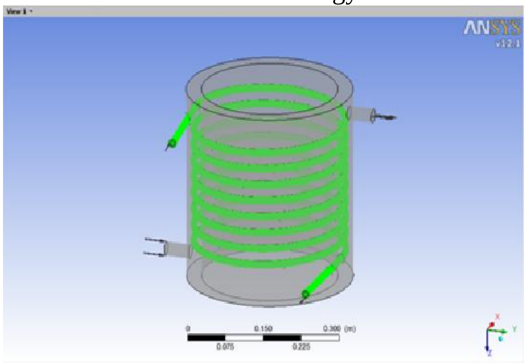

Fig.9 Domain 2

Domain 1:- Inner Cavity
Domain Type: - Stationary Domain (Fluid)
Fluid: - N_2 gas
Heat Transfer Model: - Total Energy

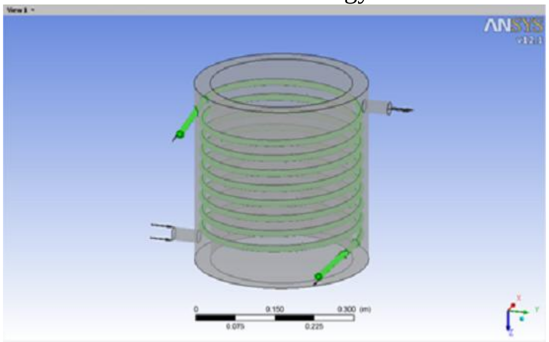

Fig.10 Domain 1

VI. Results

After using ANSYS CFX PRE for all three Domains, the outlet temperature was carried out for pitch changed helical coil heat exchanger using heat transfer model in available CFD Software ANSYS CFX 12.1.

Outlet temperature for 0.2 m/s of velocity from CFD Analysis is as given below in fig.11.

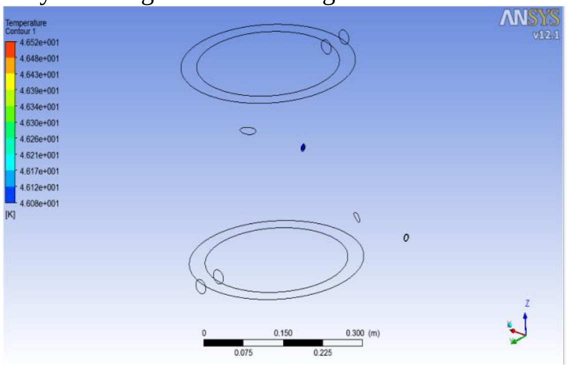

Fig.11 Temperature Contour

Same above procedure, we run above analysis for different velocity keeping inlet constant and get the results which shows in the below table:

S.No.	Outer temp. of drum(K)	Inlet Coolant Temp. (K)	Outlet Temp. of Coolant(K)	Velocity (m/s)
1	40	65	46.52	0.2
2			47.56	0.21
3			48.52	0.22
4			48.96	0.23
5			50.18	0.24
6			52.17	0.25

Table: 3. Temperature Table for all velocities

After changing the helical pitch, the heat transfer rate *Q* and inside heat transfer Coefficient h_i, using following equations:

$$Q = m \times C_p \times \Delta T$$

$$h_i = Q/ (A\times \{Tavg.\ of\ wall - Tmean\})$$

On the basis of outlet temperature, percentage increase in heat transfer rate and inside heat transfer coefficient for unchanged pitch or existing pitch (30 mm) and changed pitch (20 mm) are as given below:

Velocity (m/s)	Heat Transfer from FEM before changing the pitch (KW)	Heat Transfer from FEM after changing the pitch(KW)	Increase in heat transfer (%)
0.2	-0.0003614	-0.0005009	38.6
0.21	-0.0003664	-0.0004973	35.73
0.22	-0.0003596	-0.0004931	37.13
0.23	-0.0003670	-0.0004992	36.02
0.24	-0.0003682	-0.0004821	30.93
0.25	-0.0003692	-0.0004354	17.93

Table: 4. Comparison Table for heat transfer

Comparison of heat transfer

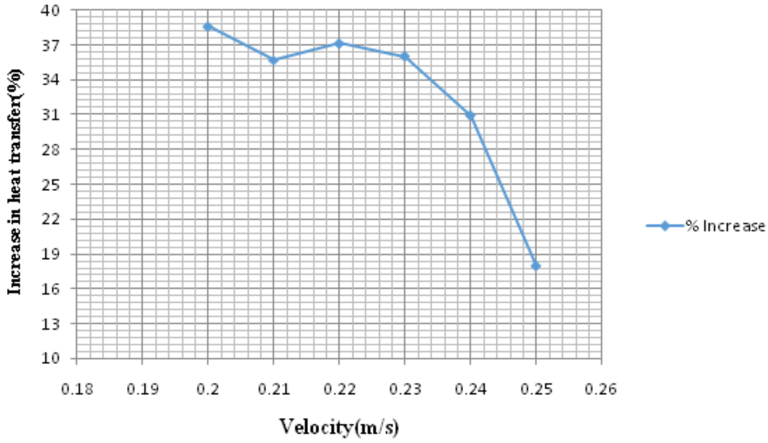

Fig. 12 percentage increase graph for heat transfer

Comparison of inside heat transfer coefficient

Velocity (m/s)	h_i from FEM before changing the pitch (KW/m^2 K)	h_i from FEM after changing the pitch (KW/m^2 K)	Increase in h_i (%)
0.2	0.3513	0.60597	72.494
0.21	0.32583	0.5266	61.62
0.22	0.29688	0.47587	60.29
0.23	0.27574	0.42881	55.51
0.24	0.26029	0.37747	45.02
0.25	0.24193	0.30038	24.16

Table: 5. Comparison Table for inside heat transfer coefficient

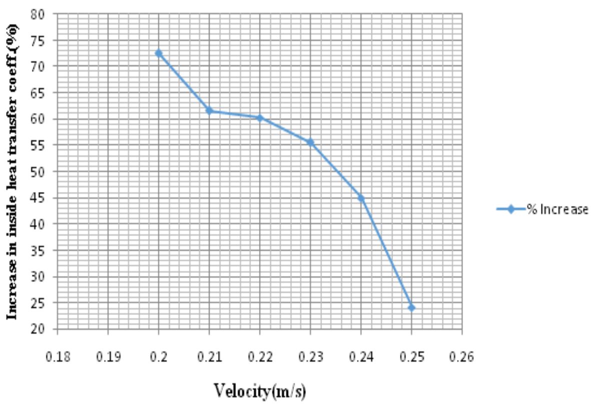

Fig. 13 percentage increase graph for heat transfer

VII. Conclusion

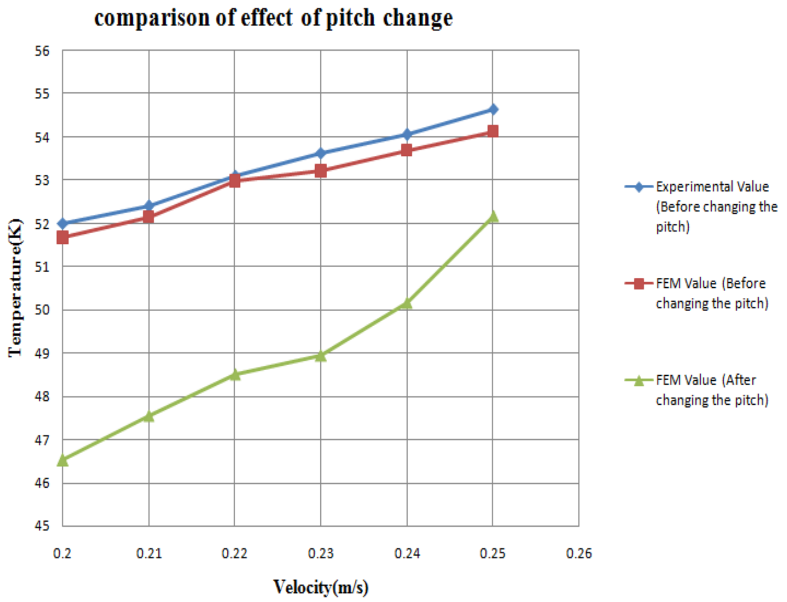

Fig. 14 Comparison graph of effect of pitch Change

From the above graph, it is seen that if the changes in coil geometry, the temperature of the coolant fluid increases instead of unchanged coil geometry. Therefore the heat transfer rate and inside heat transfer coefficient, which is based on temperature only i.e. temperature difference increases directly proportional to heat transfer rate.

From above all the analysis, we can concluded that optimize or minimize the single parameter i.e. pitch of helical coil. The heat transfer rate decreases, which is shown by negative sign in table and graph. Negative sign shows the heat transfer rate decreases or simply discharge to the atmosphere. This heat transfer decreasing shows that the nuclear storage tank is cooling by nitrogen coolant.

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