Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 04, April-2016

# Computational Fluid Dynamic Analysis for Optimization of Helical Coil Heat Exchanger

Kishor Kumar Sahu[1],
[1]PG scholar,
Department of Mechanical Engineering,
Raipur Institute of Technology, Raipur (C.G.)

Dr. N. K. Saikhedkar[2]
[2]Professor,
Department of Mechanical Engineering,
Raipur Institute of Technology, Raipur (C.G.)

***Abstract*- Helically coiled heat exchangers are used in order to obtain a large heat transfer area per unit volume and to enhance the heat transfer coefficient on the inside surface. The enhancement in heat transfer due to helical coils has been reported by many researchers by experimental setups for the estimation of the heat transfer characteristics. In this thesis the experimental results are compared with the CFD calculation results using the CFD software package ANSYS CFX used by the many researchers. Further a computational study has been accomplished to determine the effects of heat transfer in the helical coiled heat exchanger by considering the parameters like pitch length of helical coil and mass flow rate of fluids in helical coil heat exchanger. It is concluded that the CFD analysis results fairly matches with the Experimental Results. A comparison with experimental results and CFD simulations has proved that by decreasing the pitch length of helical coil and relative velocity of fluids in helical coil heat exchanger, increases heat transfer rate.**

***Key words- Helical Coil Heat Exchanger, Computational Fluid Dynamic (CFD), ANSYS CFX, Heat Transfer Rate, Heat Transfer Coefficient.***

## Nomenclature:

| | |
|---|---|
| $N_2$ | Liquid Nitrogen |
| $H_2$ | Hydrogen Gas |
| Q | Heat transfer rate |
| $T_{inlet}$, , $T_{outlet}$, $T_{mean}$ | Inlet, Outlet And Mean Temperature of Liquid Nitrogen |
| A | Cross sectional area of helical Pipe |
| A | Inner surface area of helical pipe |
| M | Mass flow rate of Liquid Nitrogen at inlet of helical pipe |
| V | Inlet velocity of Liquid Nitrogen |
| Ρ | Density of liquid Nitrogen |
| Cp | Specific heat of Liquid Nitrogen |
| ΔT | Change in temperature |
| $h_i$ | Inner Heat transfer Coefficient of helical pipe |
| N | Number of turns in helical pipe |
| L | Length of helical pipe |
| D | Inner diameter of helical pipe |

## I INTRODUCTION

A heat exchanger is a device built for efficient heat transfer from one medium to another medium. The media may be separated by a solid wall, so that they never mix, or they may be in direct contact. They are widely used in space heating, refrigeration, air conditioning, power plants, chemical plants, petrochemical plants, petroleum refineries, natural gas processing, cryogenics applications and sewage treatment. One common example of a heat exchanger is the radiator in a car, in which the heat source, being a hot engine-cooling fluid, water, transfers heat to air flowing around the radiator (i.e. the heat transfer medium).

The heat exchanger accepts two or more streams, which may flow in directions parallel or perpendicular to one another. When the flow directions are parallel, the streams may flow in the same or in opposite sense. Thus we can think of three primary flow arrangements:

a) Parallel flow
b) Counter flow
c) Cross flow

Thermodynamically, the counter flow arrangement provides the highest heat (or cold) recovery, while the parallel flow geometry gives the lowest. The cross flow arrangement, while giving intermediate thermodynamic performance, offers superior heat transfer properties and easier mechanical layout. Under certain circumstances, a hybrid cross counter flow geometry provides greater heat (or cold) recovery with superior heat transfer performance.

Helically coiled tubes can be found in many applications including food processing, nuclear reactors, compact heat exchangers, and heat recovery systems in chemical processing. Due to the extensive use of helical coils in these applications, knowledge about the pressure drop, flow patterns, and heat transfer characteristics are very important. Pressure drop characteristics are required for evaluating pump power required to overcome pressure drops to provide the necessary flow rates. These pressure drops are also functions of the curvature of the tube wall.

For design of heat exchangers that contain curved tubes, or helically coiled heat exchangers, the heat transfer and hydrodynamic characteristics needed to be known for different configurations of the coil, including the ratio of tube radius to coil radius, pitch length, Reynolds number and Prandtl number.

Heat transfer rate in helical coil is higher as compared to a straight tube heat exchanger. It required small amount of floor area compared to other heat exchangers. Larger heat transfer surface area is available. The major drawback of helical coil heat exchanger is the difficulty in predicting the heat transfer coefficients and the surface area available for heat transfer. These problems are brought on because of the lack of information in fluid-to-fluid helical heat exchangers, and the poor predictability of the flow characteristics around the outside of the coil.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 04, April-2016

Different analyses with CFD software were performed for the heat transfer enhancement in Helical Coil Type Heat Exchanger and comparison with other types of heat exchanger and factors or parameters affecting the performance of helical coil. J.S. Jayakumar[1] found that the specification of a constant temperature or constant heat flux boundary condition for an actual heat exchanger does not yield proper modelling. Hence, the heat exchanger is analyzed considering conjugate heat transfer and temperature dependent properties of heat transport media. An experimental setup is fabricated for the estimation of the heat transfer characteristics. The experimental results are compared with the CFD calculation results using the CFD package FLUENT 6.2. Based on the experimental results a correlation is developed to calculate the inner heat transfer coefficient of the helical coil. By Rahul Kharat[2], mathematical model is developed to analyze the data obtained from CFD and experimental results to account for the effects of different functional dependent variables such as gap between the concentric coil, tube diameter and coil diameter which affects the heat transfer. Optimization is done using Numerical Technique and it is found that the new correlation for heat transfer coefficient developed in this investigation provides an accurate fit to the experimental results within an error band of 3–4%.

Mandhapati Raju[3], in this paper a helical coil heat exchanger embedded in a sodium alanate bed is modeled using COMSOL. Sodium alanate is present in the shell and the coolant flows through the helical tube. A three-dimensional COMSOL model is developed to simulate the exothermic chemical reactions and heat transfer. The distribution of temperature and hydrogen absorbed in the bed for a sample case is presented. A parametric study is conducted using COMSOL-Matlab interface to determine the optimal bed diameter, helical radius and helical pitch for maximum gravimetric capacity. A research of Ahmed M. Elsayed[4] presents a CFD modeling study to investigate the laminar heat transfer through helical tubes with nanofluids. The developed CFD models were validated against published experimental results and empirical correlations in the literature. Results have shown that $Al_2O_3$ dispersed in water increases the heat transfer coefficient in helical coils by up to 4.5 times that of pure water in straight tubes at same Reynolds number. For concentrations larger than 2%, $Al_2O_3$ is more suitable for thermal systems of small thermal loads where the pumping power is not critical.

Pramod S. Purandare[5],This paper deals with the parametric analysis of the helical coiled heat exchanger with various correlations given by different researchers' for specific conditions. The parametric analysis of these various correlations with specific data is presented in this paper.

Revendra Verma, Hitesh Kumar, Satyashree Ghodk[8], 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.

## II PROBLEM FORMULATION

Capacity of Nuclear Storage Station can be increased without significant change in the circuit is possible only one way i.e. by increasing flow of Liquid Nitrogen in the nuclear storage tank. However if we increase the flow in the Helical Coil Heat Exchanger, heat transfer characteristics goes down which could be balanced by decreasing pitch of Helical Coil Heat Exchanger and decreasing the relative velocity of fluids flowing in Helical Coil Heat Exchanger.

### *2.1 Experimental Set Up*

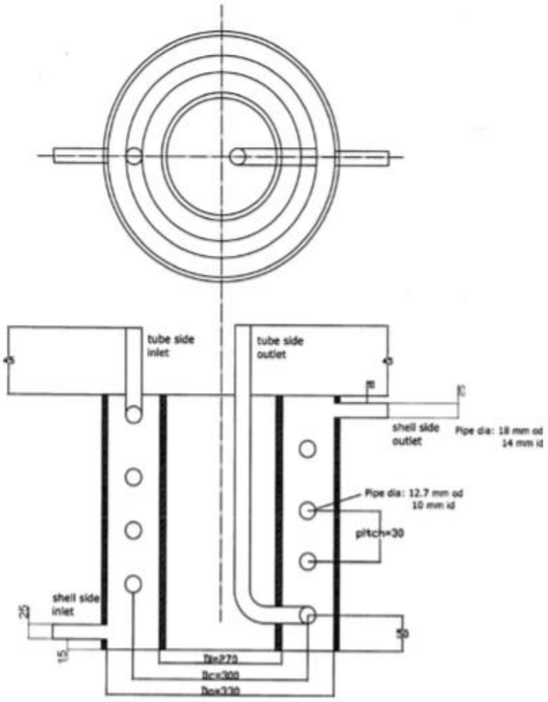


Figure 2.1: Available Experimental set up diagram

### *2.2 Helical Coil Test Section*

The pipe used to construct the helical section has 10mm I.D. and 12.7mm O.D. The tube material is SS 316. The Pitch Circle Diameter (PCD) of the coil is 300mm and tube pitch is 30mm. The remaining parts of the setup are made of SS 304.The helical coil is enclosed in a vessel to simulate the shell side of heat exchanger. The cold fluid enters the shell through the bottom connection and flows up. It leaves the shell through the nozzle at the top. The coil and the baffle are welded to a top flange in such a way that they can be replaced with another coil assembly. The helical coil test section is connected to a loop, which provides the necessary flow through the tube and shell side of the test section and the required instrumentation. A tank with electrical heaters is provided to heat the water to be circulated through the helical coil. There are three heaters, with a total power of 5000W. A controller is provided to maintain the temperature of fluid at the inlet of the test section at the set value. The hot fluid from the tank is pumped through the test section using a centrifugal pump of 1/2 hp power rating. Flow rate of hot fluid is measured using a rotameter. Both inlet and outlet temperatures of the hot fluid are measured by using Resistance Temperature Detectors and the values are available on digital displays.

*2.3 Experimental Procedure*

Measurements are taken only after the temperatures attain steady values. Experiments are conducted for six different flow rates through the coil and for three different values of temperature at the inlet of the helical pipe. During the course of each set of experiments, the flow rate through the shell side is kept constant, which ensures a constant heat transfer coefficient on the shell side. The experiment is carried out by changing the flow rate through the tube. Once a steady state is attained, values of flow rates of the hot and cold fluids, temperatures at the inlet and exit of the hot and cold fluid, and the power input to the heater and the pump are noted.

*2.4 Heat Transfer Calculation*

*2.4.1 Practical Data:*

Based on the experimental data as in Reference [8]

1. Drum fluid temperature = 40 K.
2. Average temperature of helical pipe wall = 45.23 K.
3. Inlet temperature = 65 K
4. Outlet temperature =52 K
5. Velocity of coolant = 0.2 m/s
6. Inner Diameter of Helical pipe = 0.010 m
7. Density of Liquid nitrogen = 0.86 Kg/m3
8. Length of Helical Pipe = 0.1885 m
9. Number of turns = 6

**2.4.2 Calculation:**

- Mean Temperature is given by
  $T_{mean} = \frac{T_{inlet}+T_{outlet}}{2} = \frac{65+52}{2} = 58.5$ K
- Area of Helical Pipe,
  $a = \frac{\pi}{4} X d^2 = \frac{\pi}{4} X .010^2 = 7.85 X 10^{-5}$ m$^2$
- Inner Surface area of Helical pipe
  $A = \pi dL = \pi X .01 X 0.1885 = 0.005922$ m$^2$
- Mass Flow Rate, a
  $m = a \times V \times \rho = (7.85 X 10^{-5}) X 0.2 X 0.86$
  $= 1.35 X 10^{-5}$ Kg/s
- Heat Transfer Rate,
  $Q = m \times Cp \times \Delta T$
  $= 1.35 X 10^{-5} X 2.008 X (52 - 65)$
  $= - 3.524 X 10^{-4}$ KW
- Inside Heat Transfer Co-efficient, based on the formula as in reference [8]
  $h_i = \frac{Q}{A\,(T_{avg\ of\ wall} - T_{mean})} = \frac{-3.524 X 10^{-4}}{0.005922\ (45.23-58.5)} = 0.004485$ KW/m$^2$K

Similarly, at different velocities and different mass flow rates, the heat transfer rate and inside heat transfer coefficient is calculated.

## III METHODOLOGY

In this project work a Computational Fluid dynamic Analysis has been performed in the assembly of Helical Coil Heat Exchanger. The parameter of heat exchanger and experimental result has been referred from the work of Mr. J S Jaykumar, Mr. S M Mahajani and Mr. J C Mandal[1] and for the validation of result obtained from the CFX & CFD workbench we referred the research work of Mr. Revendra Verma and Mr. Hitesh Kumar[8].

Computational fluid dynamics (CFD) study of the system starts with the construction of desired geometry and mesh for modeling the dominion. Generally, geometry is simplified for the CFD studies. Meshing is the discretization of the domain into small volumes where the equations are solved by the help of iterative methods. Modeling starts with the describing of the boundary and initial conditions for the dominion and leads to modeling of the entire system. Finally, it is followed by the analysis of the results, discussions and conclusions

*3.1 Solid Modeling and formulation of Parameter of Helical Coil Heat Exchanger*

The typical modeling process is performed by the ANSYS 15.0 workbench. We are using the design modeler workbench for modeling of any geometry in ANSYS 15.0. There are two different parts in the assembly of helical heat exchanger in which one is cylindrical wall with inlet and outlet opening for Hydrogen gas and other one consists of helical steel coil in which Liquid Nitrogen flows. The overall height of the shell is maintained at 250 mm and the outer and inner diameter of the shell is 330 mm and 270 mm respectively. The location of inlet and outlet opening is maintained as to cover the overall height of helical coil. The total height of helical coil is maintained at 165 mm and the mean coil diameter is 300 mm.

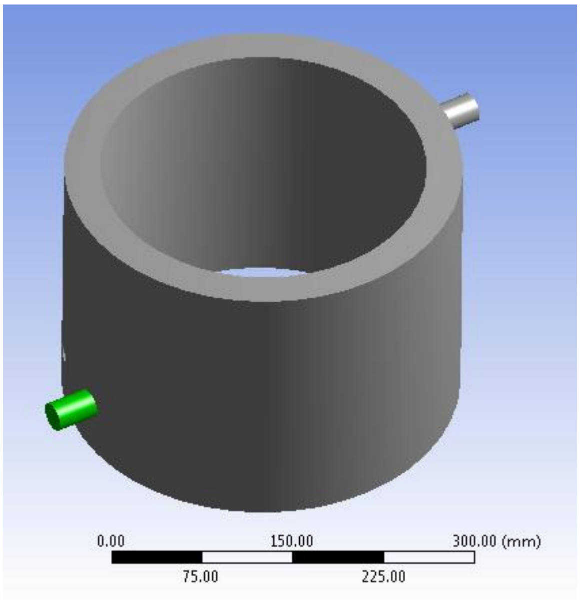


Figure 3.1: Model of Heat Exchanger Shell

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 04, April-2016

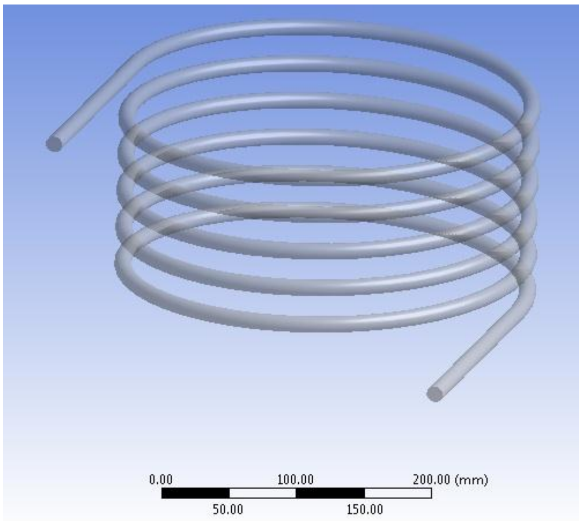


Figure 3.2: Model of Heat Exchanger Helical Coil

## 3.2 *3.2 Meshing of Helical Coil Heat Exchanger*

Initially a relatively coarser mesh is generated. This mesh contains mixed cells (Tetra and Hexahedral cells) having both triangular and quadrilateral faces at the boundaries. During the meshing process of whole body the name selection parameter has also defined to easily identify the different region of inlet and outlet.

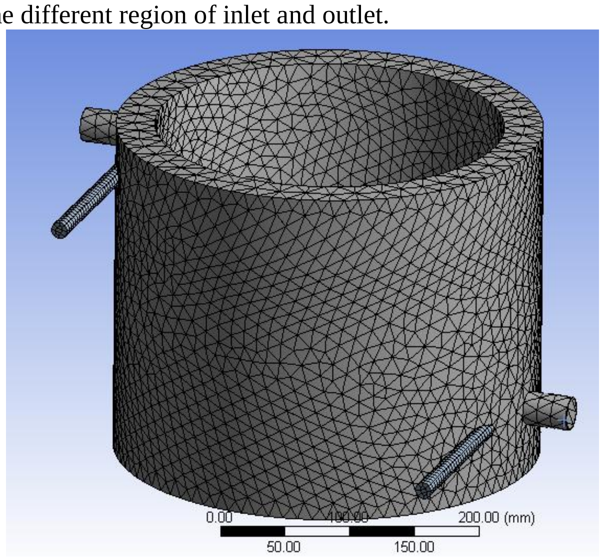


Figure 3.3: Meshing Of Helical coil Heat Exchanger

## 3.3 *3.3 Setup and Boundary Condition of Helical Coil Heat Exchanger*

In order to study the performance of helical coil heat exchanger we are using the nitrogen as a working fluid and hydrogen as coolant. When the nitrogen comes from nuclear storage station its temperature is near about 65 K which is higher as per the requirement of storage temperature. So we need to cool down the nitrogen. For this purpose we are using hydrogen as a coolant for Nitrogen. The properties of fluid flowing in the heat exchanger is given below Table (3.1)

Table 3.1: Properties of Flowing Fluids

| | Fluid | Boundary Condition Type | Value |
|---|---|---|---|
| 1 | NITROGEN | Inlet Velocity | 0.2 m/s |
| | | Inlet Temperature | 65K |
| | | Initial Pressure | 1atm |
| 2 | HYDROGEN | Inlet Velocity | 1m/s |
| | | Inlet Temperature | 40K |
| | | Initial Pressure | 1atm |

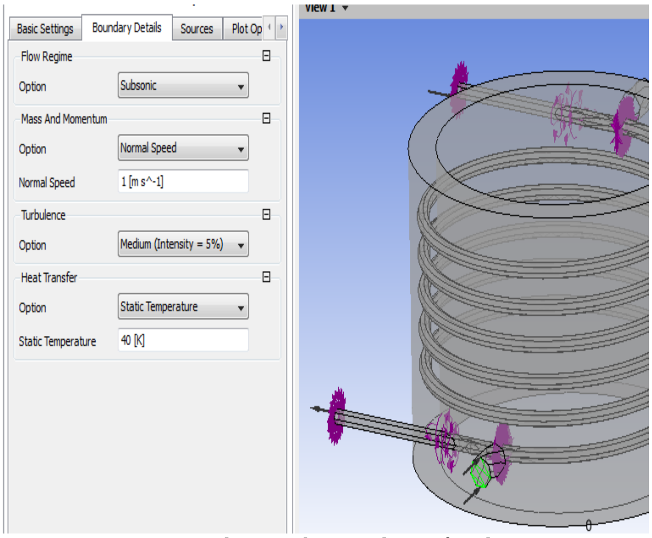


Figure 3.4: Inlet Boundary Condition of Hydrogen

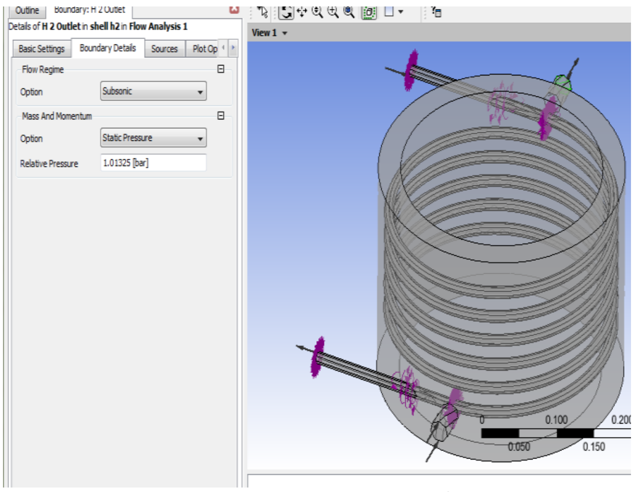


Figure 3.5: Outlet Boundary Condition of Hydrogen

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 04, April-2016

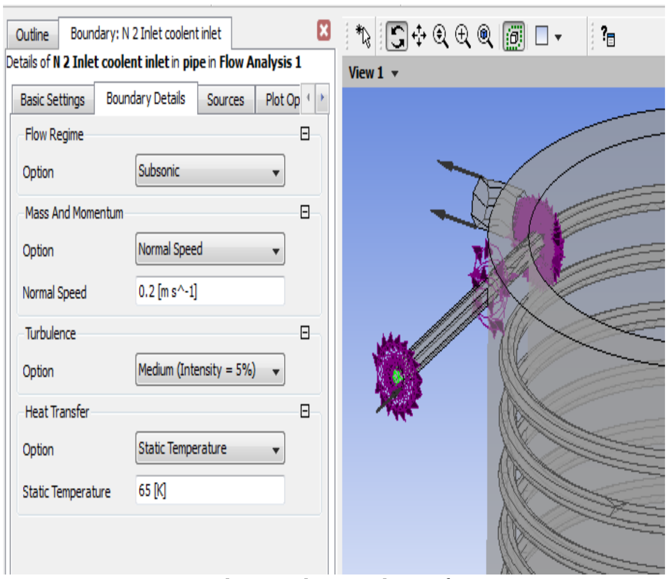


Figure 3.6: Inlet Boundary Condition of Nitrogen

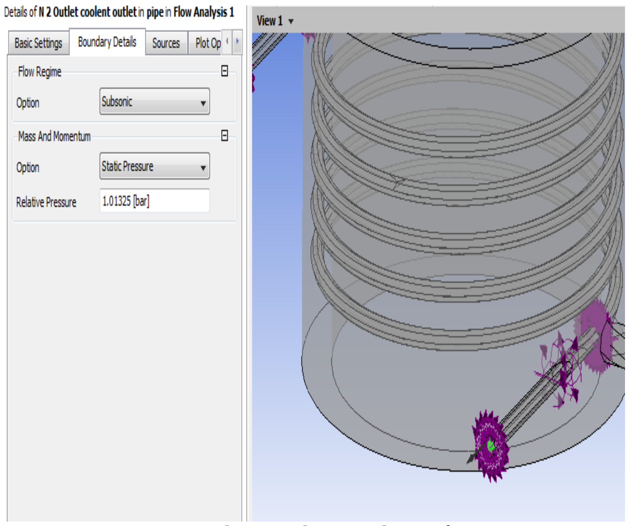


Figure 3.7: Outlet Boundary Condition of Nitrogen

## 3.4 *3.4 Solution of the Problem*

The CFX and CFD gives the solution of different fluid flow and heat flow problems based on the given boundary condition and some assumption. We perform the solution in two different phases for analysis of results. In Phase I we critically analysis the result obtained by keeping the pitch 30 mm of helical coil and variable mass flow rate of Nitrogen and similarly we again perform same analysis with same boundary condition for pitch 20 mm of helical coil and variable mass flow rate of Nitrogen.

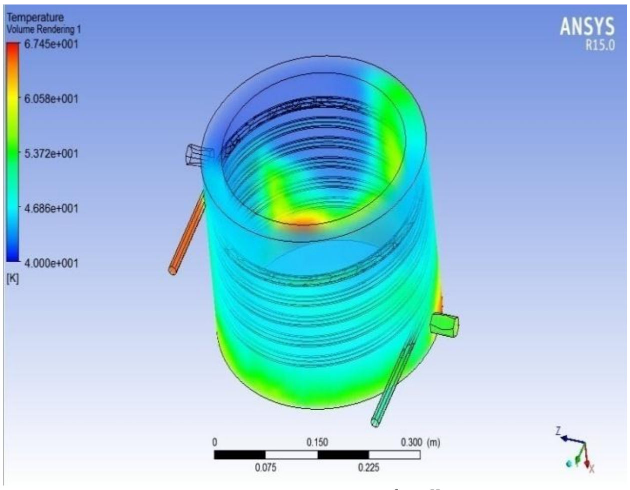


Figure 3.8: Temperature Contour for all Domains

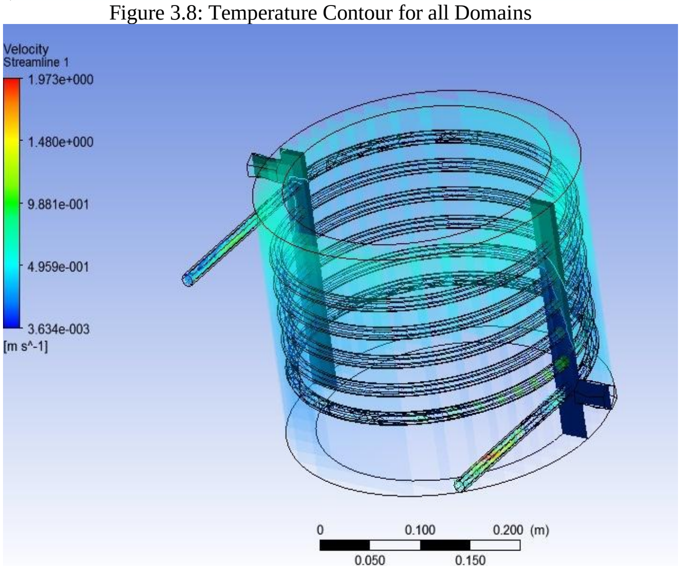


Figure3.9: Velocity profile for all domains

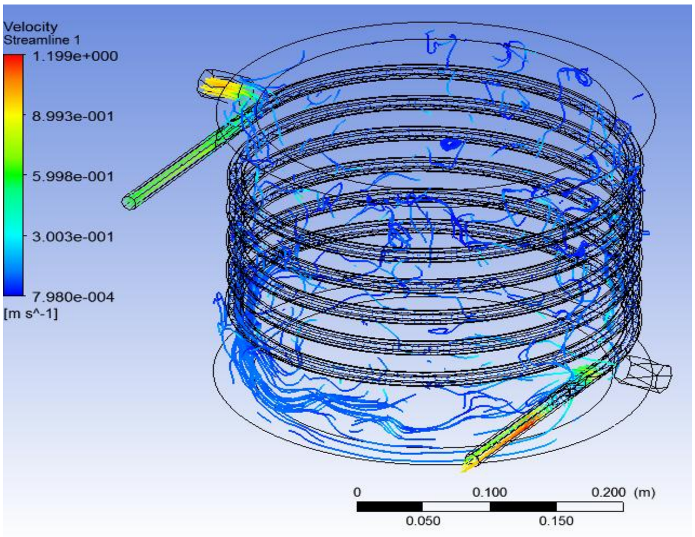


Figure 3.10: Flow Path of Hydrogen

## IV RESULT

After using ANSYS CFX analysis for all Domains, the outlet temperature of Liquid Nitrogen was carried out for Helical Coil Heat Exchanger using heat transfer model in available CFD Software ANSYS CFX 15.0.). We found the outlet temperature of Nitrogen and Hydrogen and average wall temperature at varying mass flow rate of Nitrogen for 30 mm pitch in phase I and 20mm pitch in phase II as given in Tables.

The Heat Transfer Rate (Q) and Inside Heat Transfer Coefficient (hi), using following equations:

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

$$h_i = \frac{Q}{A\,(T_{avg\ of\ wall} - T_{mean})}$$

Table 4.1: Result Obtained From Phase I

| Sr. No. | Velocity of Hydrogen (m/s) | Velocity of Nitrogen (m/s) | | Outlet Temp. of Nitrogen (K) | Average wall temperature (K) | Heat Transfer from ANSYS (KW) | hi from ANSYS (KW/m2 K) |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 0.20 | | 47.63 | 47.09 | 0.0004708 | 0.008619 |
| 2 | 1 | 0.21 | | 47.93 | 46.89 | 0.0004858 | 0.008569 |
| 3 | 1 | 0.22 | | 49.71 | 46.50 | 0.0004559 | 0.007095 |
| 4 | 1 | 0.23 | | 51.42 | 45.18 | 0.0004233 | 0.005484 |
| 5 | 1 | 0.24 | | 51.80 | 44.43 | 0.0004295 | 0.005192 |
| 6 | 1 | 0.25 | | 52.37 | 42.97 | 0.0004279 | 0.004597 |

Table 4.2: Comparison of Heat transfer rate and inner heat transfer coefficient for all velocities (for 30 mm pitch)

| Sr. No. | Velocity of Nitrogen (m/s) | Heat Transfer (KW) | | Inner Heat Transfer coefficient hi (KW/m²K) | |
|---|---|---|---|---|---|
| | | from ANSYS | from EXPERIMENT | from ANSYS | from EXPERIMENT |
| 1 | 0.20 | 0.0004708 | 0.0003525 | 0.008619 | 0.004485 |
| 2 | 0.21 | 0.0004858 | 0.0003584 | 0.008569 | 0.004187 |
| 3 | 0.22 | 0.0004559 | 0.0003546 | 0.007095 | 0.003864 |
| 4 | 0.23 | 0.0004233 | 0.0003542 | 0.005484 | 0.003483 |
| 5 | 0.24 | 0.0004295 | 0.0003563 | 0.005192 | 0.003304 |
| 6 | 0.25 | 0.0004279 | 0.0003508 | 0.004597 | 0.003005 |

Table 4.3: Results Obtained From Phase II

| Sr. No. | Velocity of Hydrogen (m/s) | Velocity of Nitrogen (m/s) | Outlet Temp. of Nitrogen (K) | Average wall temperature (K) | Heat Transfer from ANSYS (KW) | hi from ANSYS (KW/m2 K) |
|---|---|---|---|---|---|---|
| 1 | 1 | 0.20 | 40.88 | 48.45 | 0.000654 | 0.014767 |
| 2 | 1 | 0.21 | 42.45 | 47.45 | 0.000642 | 0.010375 |
| 3 | 1 | 0.22 | 43.98 | 46.52 | 0.0006269 | 0.007974 |
| 4 | 1 | 0.23 | 45.77 | 45.62 | 0.0005996 | 0.006219 |
| 5 | 1 | 0.24 | 45.92 | 45.93 | 0.0006207 | 0.006598 |
| 6 | 1 | 0.25 | 47.47 | 43.69 | 0.0005940 | 0.004797 |

Table 4.4: Comparison of Heat transfer rate and inner heat transfer coefficient for all velocities (for 20 mm pitch)

| Sr. No. | Velocity of Nitrogen (m/s) | Heat Transfer (KW) | | Inner Heat Transfer coefficient hi (KW/m²K) | |
|---|---|---|---|---|---|
| | | For 30 mm pitch | For 20 mm pitch | For 30 mm pitch | For 20 mm pitch |
| 1 | 0.20 | 0.0004708 | 0.000654 | 0.008619 | 0.014767 |
| 2 | 0.21 | 0.0004858 | 0.000642 | 0.008569 | 0.010375 |
| 3 | 0.22 | 0.0004559 | 0.0006269 | 0.007095 | 0.007974 |
| 4 | 0.23 | 0.0004233 | 0.0005996 | 0.005484 | 0.006219 |
| 5 | 0.24 | 0.0004295 | 0.0006207 | 0.005192 | 0.006598 |
| 6 | 0.25 | 0.0004279 | 0.0005940 | 0.004597 | 0.004797 |

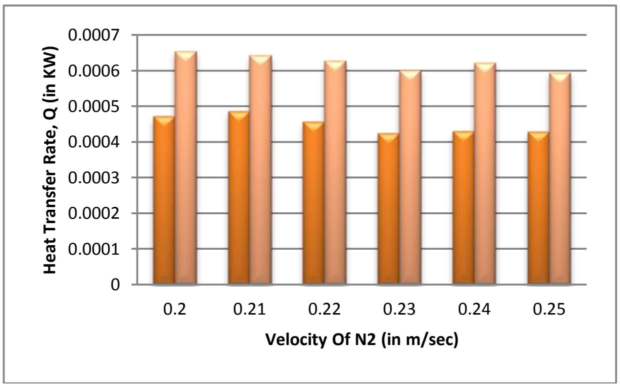


Figure 4.1: Comparison of Heat transfer rate for 30 mm and 20 mm pitch

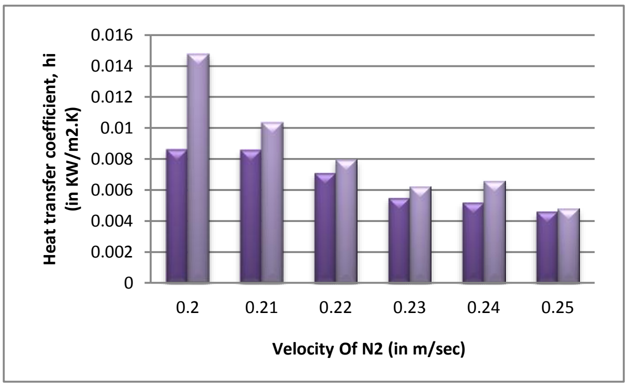


Figure 4.2: Comparison of Inner Heat transfer Coefficient for 30 mm and 20 mm pitch

On the basis of number of iteration obtained in design of experiment method we concluded that the iteration no 156 gives the optimum result on the outlet of coolant. At this point the NITROGEN outlet temperature is 40.79 K with 20 mm pitch.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 04, April-2016

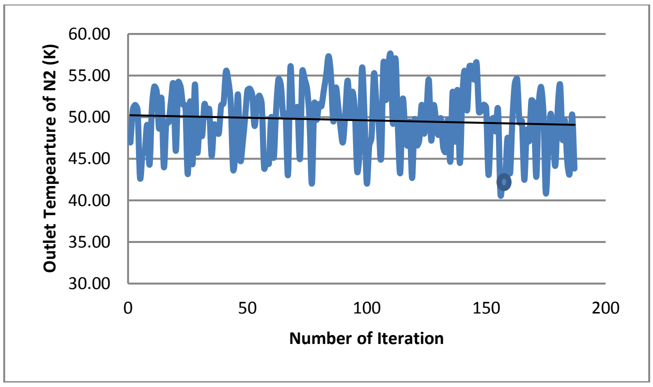


Figure 4.3: Graph for Optimum Value of Output Temperature

Above results show that the heat transfer rate and Heat transfer coefficient may be improved by decreasing the pitch length of helical pipe of helical coil heat exchanger. Results of research also predict that by increasing the mass flow rate of fluids, there is miner variation in heat transfer rate.

## V CONCLUSIONS

From the literature review, it was found that the concept of helical coils and their enhanced heat transfer characteristics have better heat and mass transfer than straight tubes. In most of the literature, a CFD modeling is used to investigate the heat transfer through helical tubes. In this work, the optimization of helical coil heat exchanger takes place. We have taken only one variable or parameter to optimize the helical coil heat exchanger i.e. helical coil pitch. Entail setup cost may approximately 45 Lakh Indian rupees. Due to this reason, we cannot fabricate this setup but instead of this, we simulate the experiment with CFD software. In this experiment, the helical coil heat exchanger has a constant coil pitch i.e. 30 mm coil pitch. Due to high cost, we can't modify this experimental setup but instead of this, we use the CFD simulation and change only one parameter i.e. coil pitch of 20 mm. We can easily simulate the parameters of helical coil heat exchanger in CFD software without any modification in experimental setup.

Although the application of CFD in the thermal based industries and power plants will benefit the understanding of the dynamics and physics of a thermal analysis operation and thus aid in the optimization and design of existing equipment, constraints are the requirement for faster, easier and less expensive CFD techniques. In CFD software development will turn automatic design and optimization in realities and the development of web based CFD will allow more people to access the technology. All these developments will contribute CFD to becoming a mature discipline and a powerful engineering tool. As a result, more widespread and rapid adoption of the use of CFD in the thermal engineering will take place in future.

## VI FUTURE SCOPE

The current research work is concentrated on the maximization of amount of heat transfer rate from one fluid to another fluid by creating different configuration of input parameters. During the project work we found that the velocity rate of hot and cold fluid can also play an important role in case of optimization of heat transfer. Present work can also extend in terms of changing the diameter of helical coil and also by changing the diameter of pitch diameter.

The present work using the genetic algorithm for Design of Experiment, it may also do by using some other algorithms such as SAA, Fuzzy Inference Systems Artificial Neural Network and Multi Objective Genetic Algorithms. A comparison can be made in terms of heat transfer amongst different optimization techniques.

## VII REFERENCES

[1] J.S. Jayakumar, S.M. Mahajani, J.C. Mandal, P.K. Vijayan, Rohidas Bhoi, Experimental and CFD estimation of heat transfer in helically coiled heat exchangers, chemical engineering research and design 86 (2008) 221–232.

[2] Rahul Kharat, Nitin Bhardwaj, R.S. Jha, Development of heat transfer coefficient correlation for concentric helical coil heat exchanger, International Journal of Thermal Sciences 48 (2009) 2300–2308.

[3] Mandhapati Raju, Sudarshan Kumar, Modeling of a Helical Coil Heat Exchanger for Sodium Alanate Based On-board Hydrogen Storage System, Excerpt from the Proceedings of the COMSOL Conference 2010, Boston.

[4] Ahmed M. Elsayed, Raya K. AL-Dadah, Saad Mahmoud, Abdel-Fattah Mahrous, Numerical Investigation of Laminar Flow Heat Transfer Through Helically Coiled Tubes Using Al2O3 Nanofluid, 3rd Micro and Nano Flows Conference, Thessaloniki, Greece, 22-24 August 2011.

[5] Pramod S. Purandare, Mandar M. Lele, Rajkumar Gupta, Parametric Analysis of Helical Coil Heat Exchanger, International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181, Vol. 1 Issue 8, October – 2012.

[6] Ashok B. Korane, P.S. Purandare, K.V.Mali, Heat transfer analysis of helical coil heat exchanger with circular and square coiled pattern, IJESR/ ISSN 2277-2685/June 2012/ Volume-2/Issue-6/Article No-3/413-423

[7] M. M. Abo Elazm, A. M. Ragheb, A.F.Elsafty, M. A.Teamah, Numerical investigation for the heat transfer enhancement in helical cone coils over ordinary helical coils, Journal of Engineering Science and Technology, Vol. 8, No. 1 (2013) 1 – 15.

[8] Revendra Verma, Hitesh Kumar, Satyashree Ghodke, A Comparative Analysis of Thermal Characteristics Between Experimental Value and FEM Value in Helical Coil Heat Exchanger, International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181, Vol. 2 Issue 11, November – 2013.

[9] T. J. Chung, University of Alabama in Huntsville, Computational Fluid Dynamics, 2002.