International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 11, November - 2013

A Comparative Analysis of Thermal Characteristics Between Experimental Value and FEM Value in Helical Coil Heat Exchanger

Revendra Verma[1], Hitesh Kumar [2], Satyashree Ghodke[3]
[1]PG Scholar, Department of Mechanical Engineering,
Technocrats Institute of Technology, Bhopal (M.P.)
[2]Associate Professor, Department of Mechanical Engineering,
TIT Group of Institutions, Bhopal (M.P.)
[3]Associate Professor & Head Of Department, Department of Mechanical Engineering,
Technocrats Institute of Technology, Bhopal (M.P.)

Abstract

Helical coils are used for heat transfer enhancement in heat exchangers. While the thermal characteristics of helical coil heat exchangers available in the literature, there are no any published paper in which the comparative analysis of thermal characteristics between experimental and FEM value. In this paper, the constraints are only velocity and mass flow rate. For this, different heat transfer rates and inner heat transfer coefficients are calculated which is based on experimentation and compared with the FEM value. FEM value is nothing, it is CFD value. Thermal characteristics are compared for various boundary conditions in helical coils. FEM calculation results using the CFD package ANSYS CFX 12.1.

Index Terms - Helical coil Heat exchanger, CFD or computational fluid dynamics, Solid works 2009, ANSYS CFX 12.1, FEM or Finite Element Method.

1. INTRODUCTION

Helical coils have been long and widely used as heat exchanger in Heating, Ventilating and Air Conditioning (HVAC), chemical processing, petrochemical engineering and nuclear reactor plants etc. Helical coils have been shown to be effective in enhancing single phase heat transfer (Kumar et al., 2006), boiling heat transfer (Wongwises and Polsongkram, 2006) and condensation heat transfer (Wongwises and Polsongkram, 2006b; Shao et al., 2007).

The present investigation is a kind of compound heat transfer enhancement techniques, because the two passive techniques such as helical coil, nanofluids are taken together to enhance heat transfer. In particular, it can be applied where space is limited and for achieving better heat transfer performance. Passive techniques which do not require any external power such as treated surfaces, rough surfaces, extended surfaces, swirl flow devices, displaced enhancement devices, coiled tube, surface tension device, additives for liquids, and additives of gases.

Dean [4] proposed a dimensionless number which relates inertia force and centrifugal force in flow through a curved pipe or channel. Dean number measures the secondary flow and effect of curvature of bend/coil on heat transfer rate.

Dean Number (De) is calculated as

$De = Re \times (d/D)^{0.5}$

Where, d is diameter of the tube,

D is curvature diameter of the coil,

The two-phase flow of a steam-water mixture in a helical coil was studied experimentally by Guo et al. [5]. Inagaki et al. [6] studied the outside heat transfer coefficient for helically coiled bundle for Re in the range of 6000 to 22,000. Yan Ke et al. [7] have investigated the helical cone tube bundles both numerically and still some foregoing experiments, the authors found that the cone angle has a significant effect on enhancing the heat transfer coefficient, also they have found that the pitch has nearly no effect on the heat transfer.

In this work, it is proposed to generate correlations for inner heat transfer coefficient considering fluid–fluid heat exchange in a helically coiled heat exchanger. An experimental setup is built for carrying out the heat transfer studies representing the equipment under study. For further details of the equipment and its applications, refer to Jayakumar and Grover (1997). In addition, the heat transfer phenomena in the exchanger are analyzed numerically using a commercial CFD code FLUENT Version 6.2 (2004). In contrast to the earlier similar analyses, instead of specifying an arbitrary boundary condition, heat transfer from hot fluid to cold fluid is modelled by considering both inside and outside convective heat transfer and wall conduction. In these analyses, we have used temperature dependent values of thermal and transport properties of the heat transfer medium, which is also not reported earlier. The numerical predictions are verified against the experimental results.

Helical coil heat exchangers have also been used for hydrogen storage applications. Various storage concepts and heat exchanger designs, including a helical coil heat exchanger design, have been proposed by Ranong for sodium alanate based hydrogen storage beds. However, detailed modeling of a helical coil heat exchanger has not been reported. Recently, an experimental study has been conducted at Purdue University for a helical coil heat exchanger for Ti1.1CrMn, a high pressure metal hydride alloy. The heat exchanger consisted of a 3/8th inch helical stainless steel tube with six rings and a helical radius of 39 mm. In our study, focus is on detailed COMSOL modeling of

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 11, November - 2013

a helical coil heat exchanger for a sodium alanate based hydrogen storage system.

Geometry of helical coil heat exchanger

Fig. 1 gives the schematic of a helical coil. The pitch circle diameter of the coil is denoted by d_{pc}. The coil has a diameter of d_c (measured between the centres of the pipes), while the distance between two adjacent turns, called pitch is h. The angle, which projection of one turn of the coil makes with a plane perpendicular to the axis, is called the helix angle.

.

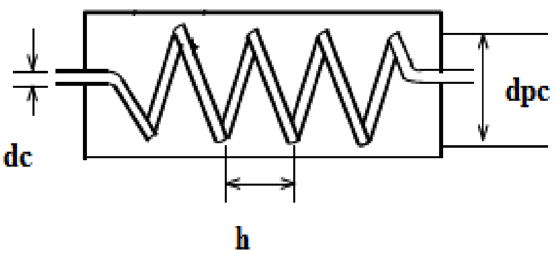

Fig. 1 Geometry of Helical Coil

Dean Number is a dimensionless number which relates inertia force and centrifugal force in flow through a curved pipe or channel. Dean number measures the secondary flow and effect of curvature of bend/coil on heat transfer rate.
Dean Number (De) is calculated as
$De = Re \times (d/D)^{0.5}$
Where, d is diameter of the tube,
D is curvature diameter of the coil,
Where, *Re* is the Reynolds number = $2ru_{av}\rho/\mu$.
It has been widely observed that the flow inside coiled tubes remains in the viscous regime up to a much higher Reynolds Number than that for straight tubes. The curvature-induced helical vortices (Dean Vortex) tend to suppress the onset of turbulence and delay transition. The critical Reynolds Number, which describes the transition from laminar to turbulent flow, is given by some correlations; the following correlation is given by Srinivasan:

$$Re_{cr} = 2100 \times (1 + 12\sqrt{a/R})$$

Dennis and Ng [8] numerically studied laminar flow through a curved tube using a finite difference method with emphasis on two versus four vortex flow conditions. They ran simulations in the Dean range of 96 to 5000. The four vortex solutions would only appear for a Dean number greater than 956. Dennis and Riley [9] developed an analytical solution for the fully developed laminar flow for high Dean Numbers. Though they could not find a complete solution to the problem, they stated that there is strong evidence that at high Dean Numbers the flow develops into an inviscid core with a viscous boundary layer at the pipe wall.

2. Experimental setup

2.1 Experimental construction design

The test section of helical coil is connected to a loop, which provides the necessary flow through the tube and shell side of the test section and the required instrumentation.
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. A controller is provided to maintain the temperature of water 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. In this experimental setup, the digital displays are available to show the inlet and outlet temperatures of the hot fluid, which are measured by using RTDs.

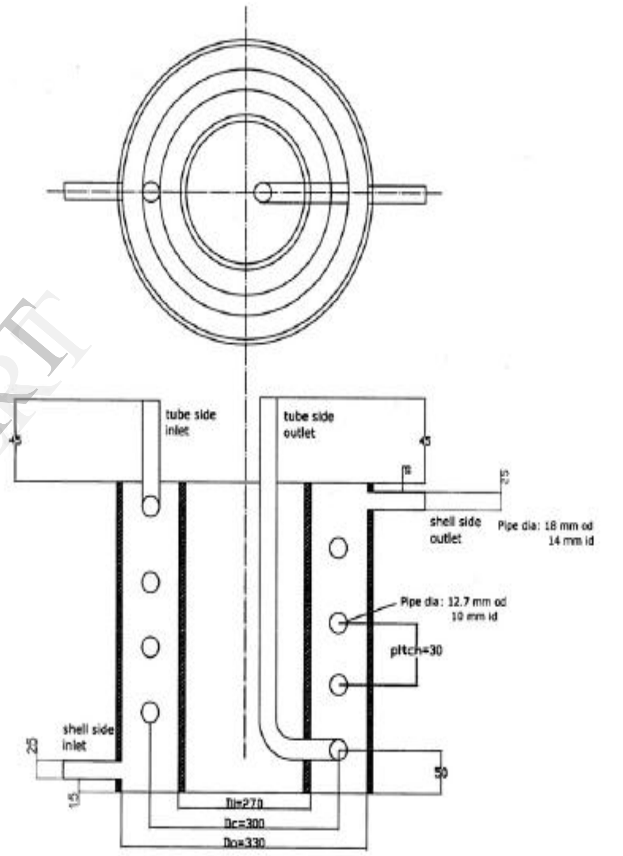

Fig.2 Available setup for experiment

Cooling water from a constant temperature tank is circulated through the shell side. Its flow rate, inlet and outlet temperatures are measured.

2.2 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 constant value of temperature at the inlet of the helical pipe. During the course of each set of experiments, the flow rate is constant through shell side which ensures a constant heat transfer coefficient on the shell side but the flow rate is variable 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.

2.3 Experimental Calculations

In present study, the heat transfer rate, *Q*, was calculated from the temperature data using the following equation.
The heat transfer *Q* was calculated with,

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

and inside heat transfer coefficient h_i was calculated with,

$$h_i = Q/ (A\times \{T_{avg.} \text{ of wall} - T_{mean}\})$$

From the experimental data, on the basis of outlet temperature, heat transfer rate and inside heat transfer coefficient calculations are given below:

Velocity (m/s)	Toutlet (K)	Mass flow rate (kg/s)	Q (KW)	hi (KW/m^2.K)
0.2	52	1.35E-5	-0.0003524	0.33831
0.21	52.4	1.42 E-5	-0.0003593	0.31675
0.22	53.11	1.49 E-5	-0.0003557	0.29241
0.23	53.64	1.55 E-5	-0.0003535	0.26227
0.24	54.05	1.62 E-5	-0.0003562	0.24925
0.25	54.65	1.69 E-5	-0.0003512	0.22704

Table: 1. Calculation Table for All Velocity

3. Modelling of helical coil heat exchanger in Solidworks 2009

After performing Experiments, the modelling is done on the Solid works 2009 version.
Solidworks is a Parasolid-based solid modeler, and utilizes a parametric feature-based approach to create models and assemblies. In short solid works is a feature based parametric solid modeling system with many extended design and manufacturing applications.

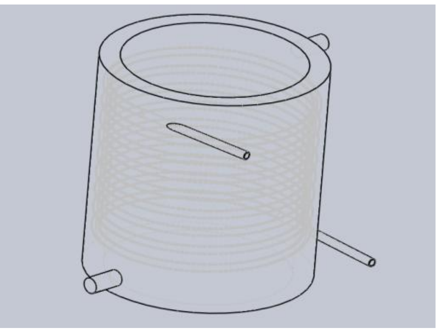

Fig. 3 3D Cavity model of Helical Coil Heat Exchanger

After creating 3D model in Solidworks, it saves as IGES Format.

4. FEM analysis of helical coil heat exchanger

Computational Fluid Dynamics (CFD) software approaches the Finite Element Method (FEM), i.e. the Computational Fluid Dynamics software solve the Node- Element Problems. So this method is also known as Finite Element method or simply FEM Analysis.
Computational Fluid Dynamics (CFD) provides a qualitative (and sometimes even quantitative) prediction of fluid flows by means of

- Mathematical modeling (partial differential equations)
- Numerical methods (discretization and solution techniques)
- Software tools (solvers, pre- and post processing utilities)

These equations are then discretized to produce a numerical analogue of the equations. The domain is then divided into small grids or elements. Finally, the initial conditions and the boundary conditions of the specific problem are used to solve these equations. The solution method can be direct or iterative. In addition, certain control parameters are used to control the convergence, stability, and accuracy of the method.
Computational fluid dynamics in principle, allows the practical solution of the Exact Governing equitation of applied Engineering problems.
The 3D geometry of the helical coil heat exchanger and flow domain was created in Solid works 2009. A grid was generated within the flow domain. Unstructured Grid was used for meshing. Generated grid is an unstructured mesh consisting total number of Nodes (1161278) and total number of Elements (3901305). Numerical conditions need to be applied at the boundaries of the fluid domains.
Details of the refined mesh are shown in fig.4.

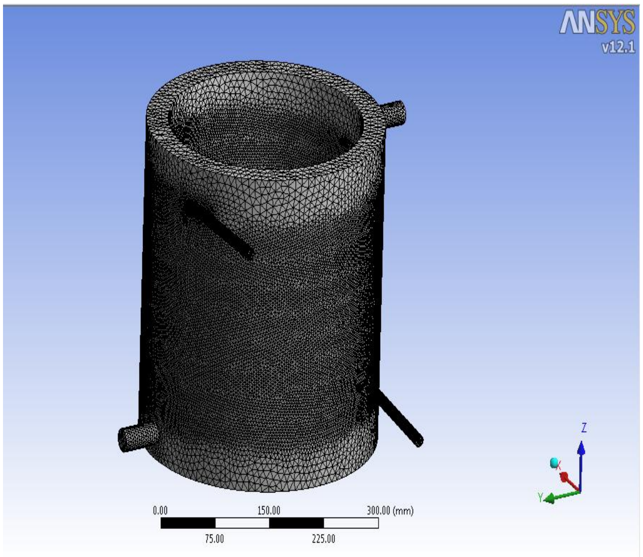

Fig.4 Meshing Geometry in ANSYS CFX 12.1

It saves as mesh file as *.cmdb format.

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.

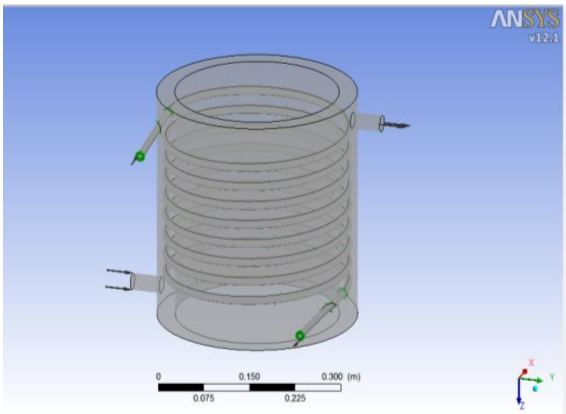

Fig.5 Helical Coil Heat Exchanger in ANSYS CFX PRE

Define all three Domains:-

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

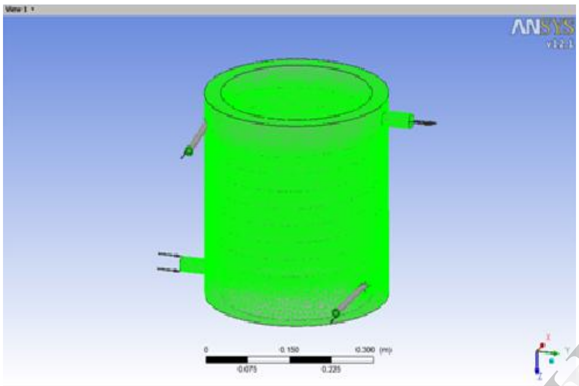

Fig.6 Domain 3

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

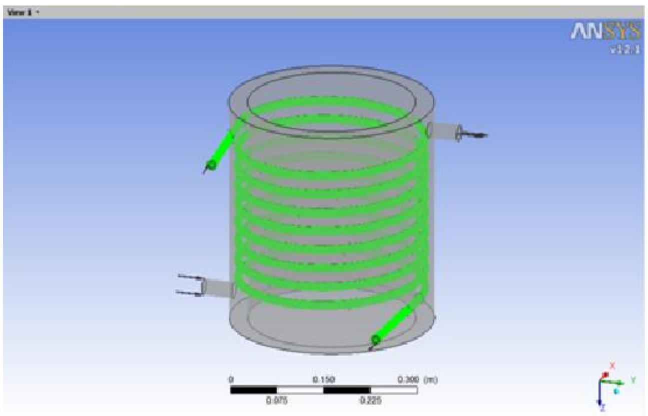

Fig.7 Domain 2

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

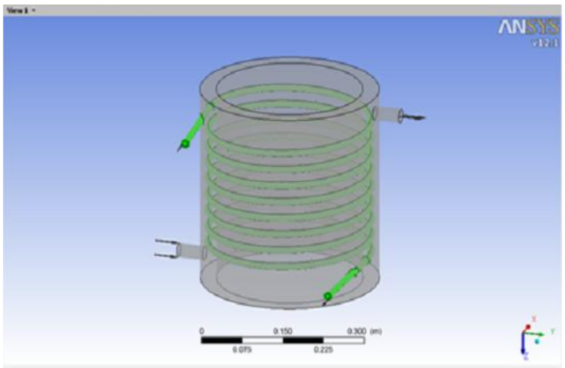

Fig.8 Domain 1

5. Results

After using ANSYS CFX PRE for all three Domains, the outlet temperature was carried out for 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 figure 9.

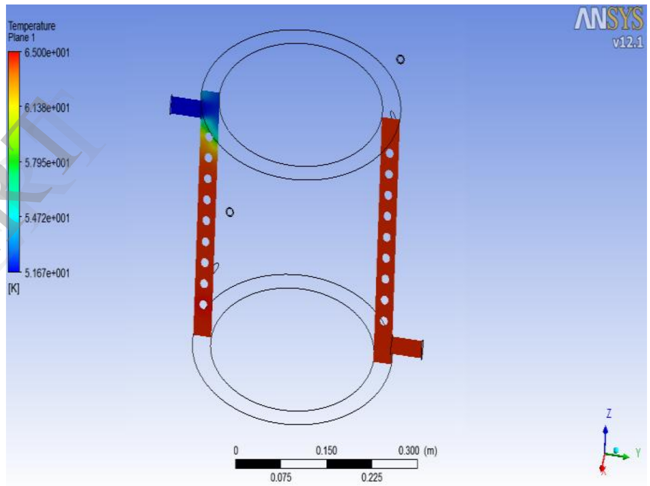

Fig. 9 Temperature Contour

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			51.67	0.2
2			52.15	0.21
3	40	65	52.98	0.22
4			53.21	0.23
5			53.68	0.24
6			54.12	0.25

Table: 2. Temperature Table for all velocities

The heat transfer rate Q and inside heat transfer Coefficient h_i, using following equations:

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

$$h_i = Q / (A \times \{T_{avg.}\ \text{of wall} - T_{mean}\})$$

On the basis of outlet temperature, heat transfer rate and inside heat transfer coefficient calculations are given below:

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: 3. Q and h_i Table for all velocities

Comparison of heat transfer rate at constant velocity:

Velocity (m/s)	Heat Transfer from EXPERIMENT (KW)	Heat Transfer from FEM (KW)	Increase in heat transfer (%)
0.2	-0.0003524	-0.0003614	2.554
0.21	-0.0003593	-0.0003664	1.976
0.22	-0.0003557	-0.0003596	1.096
0.23	-0.0003535	-0.0003670	3.819
0.24	-0.0003562	-0.0003682	3.369
0.25	-0.0003512	-0.0003692	5.125

Table: 4. Comparison of Q for all velocities

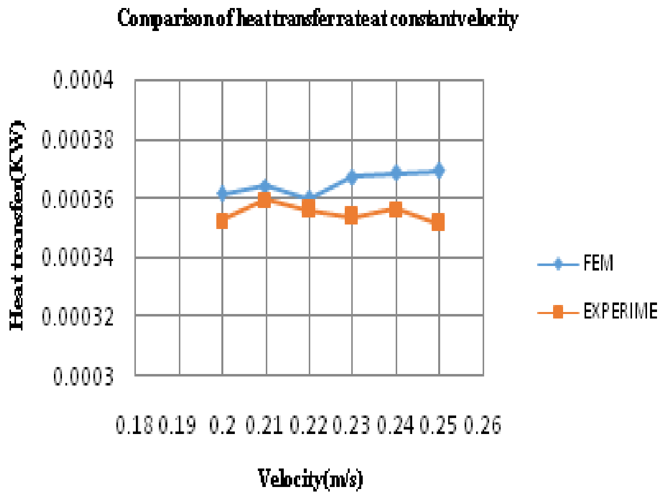

Fig. 10 Comparison graph of Q

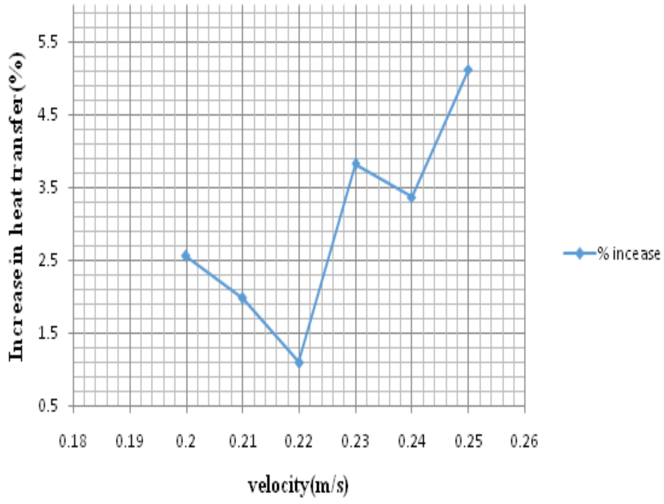

Fig. 11 percentage increase of Q with velocity

Comparison of inside heat transfer coefficient (h_i) at constant velocity:

Velocity (m/s)	h_i from EXPERIMENT (KW/m^2 K)	h_i from FEM (KW/m^2 K)	Increase in h_i (%)
0.2	0.33831	0.35130	3.84
0.21	0.31675	0.32583	2.87
0.22	0.29241	0.29688	1.53
0.23	0.26227	0.27574	5.14
0.24	0.24925	0.26029	4.43
0.25	0.22704	0.24193	6.558

Table: 5. Comparison of Q for all velocities

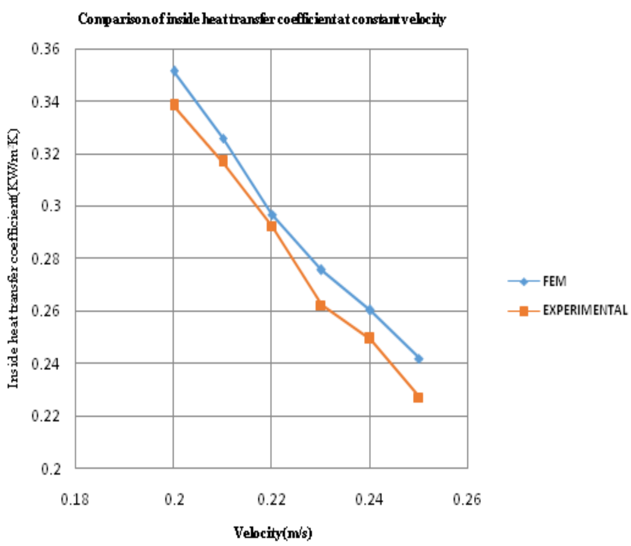

Fig. 12 Comparison graph of h_i

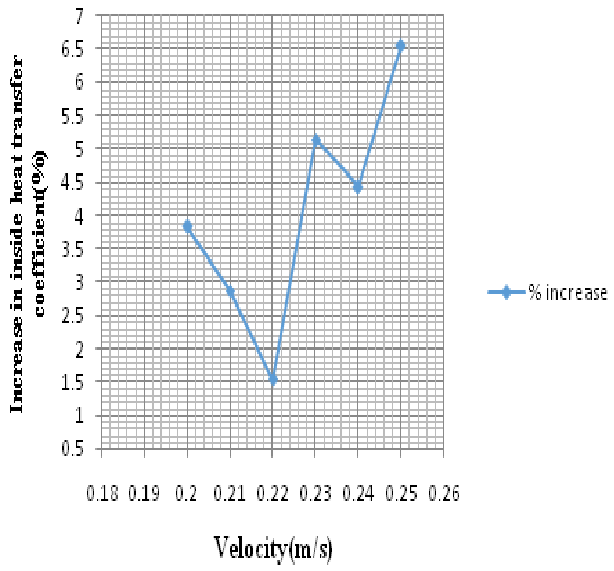

Fig. 13 percentage increase of h_i with velocity

6. Conclusion

It is concluded that the FEM analysis results matches with the Experimental Results. From the above analysis, there are two variables i.e. velocity and mass flow rate. The outlet temperature of the coolant (liquid nitrogen) increases with increasing the velocity and mass flow rate. In this experiment or analysis specific heat of coolant, outer temperature of drum and inlet coolant temperature is constant through the experiments or FEM analysis. This shows that FEM Analysis is a powerful tool to replace costly experiment and lengthy calculation.
A comparison with experimental results and FEM analysis has proved that for increasing mass flow rate of coolant or liquid nitrogen without increasing Overall circuit of Nuclear Reactor. By increasing velocity in existing helical coil heat exchanger and analyzed a result which shows that as the velocity increase thermal characteristics i.e. heat transfer rate decreases and inside heat transfer rate also decreases.

7. References

[1] Kumar,V., Saini, S., Sharma, M., Nigam, K.D.P. 2006. Pressure drop and heat transfer study in tube-in-tube helical heat exchanger. Chem. Eng. Sci. 61, 4403-4416.

[2] Wongwises, S., Polsongkram, M., 2006a. Evaporation heat transfer and pressure drop of HFC-134a in a helically coiled concentric tube-in-tube heat exchanger. Int. J. Heat Mass Transfer 49(3-4), 658- 670.

[3] Wongwises, S., Polsongkram, M., 2006b. Condensation heat transfer and pressure drop of HFC-134a in a helically coiled concentric tube-in-tube heat exchanger. Int. J. Heat Mass Transfer 49 (23-24), 4386–4398.

[4] Dean W.D., Note on the motion of fluid in a curved pipe, Philos.Mag.4 (1927)208.

[5] Guo, L., Chen, X., Feng, Z., and Bai, B., (1998) "Transient convective heat transfer in a helical coiled tube with pulsating fully developed turbulent flow", International Journal of Heat and Mass Transfer, Vol. 41, pp. 2867-2875.

[6] Inagaki, Koiso, Y., Takumi, H., Ioka, H., and Y. Miyamoto, (1998) "Thermal hydraulic study on a high-temperature gas heat exchanger with helically coiled tube bundles", Nuclear Engineering and Design, Vol. 185, pp. 141-151.

[7] Ke, Y.; Pei-qi, G.; Yan-cai, S.; and Hai-tao, M. (2011). Numerical simulation on heat transfer characteristic of conical spiral tube bundle. Applied Thermal Engineering, 31(2-3), 284-292.

[8] Dennis S.C.R., Ng M.: 1982, Dual solutions for steady laminar flow through a curved tube, Quarterly Journal of Mechanics and Applied Mathematics, Vol. 35 (3):305-324.

[9] Dennis S.C.R., Riley N.: 1991, On the fully developed flow in a curved pipe at large Dean number. Proc.R.Soc. London Ser. A 434 (1891), 473-478.