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Cfd analysis of heat transfer in a compact helical coil heat exchanger using fluent

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ABSTRACT

A helically coil-tube heat exchanger is generally applied in industrial applications due to its compact structure, larger heat transfer area and higher heat transfer capability, etc. The importance of compact heat exchangers (CHEs) has been recognized in aerospace, automobile, gas turbine power plants, and other industries for the last 60 years or more due to several factors as mentioned above. However flow and heat transfer phenomena related to helically coil-tube heat exchanger are very sophisticated. A computational fluid dynamics (CFD) methodology using ANSYS FLUENT is used here to investigate effects of different curvature ratio on the heat transfer characteristics in a helically coil-tube. Simulation has been done for different curvature ratios of a helical coil tube by varying different inlet conditions like velocity-inlet and pressure-inlet for different flow and heat transfer condition. Based on the simulation results, the complicated phenomena occurred within a helical coil-tube can be reasonably captured, including heat transfer behaviors from the entrance region, etc. Experimental result is compared with the simulated data obtained.

For all the cases considered in this work, heat transfer coefficient, Nusselt number, pressure drop, Colburn factor and fRe are being computed and studied to analyze the heat transfer characteristics of a helical coil tube.

***Keywords*— Relaxation factors, Nusselt number, pressure drop, Colburn factor and fRe.**

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I. INTRODUCTION

Heat exchanger is a device that continuously transfers heat from one medium to other medium in order to carry process energy.

Heat exchangers are used in various systems for:

a) recovering heat directly from one flowing medium to another or via a storage system, or indirectly via a heat pump or heat transformer.

b) heating or cooling a process steam to the required temperature for a chemical reaction (this can also be direct or indirect).

c) enabling, as an intrinsic element, a power, refrigeration or heat pumping process, that is interchanging heat between a hot source or steam with the working fluid and with the low temperature heat sink (or source).

For efficiency, heat exchangers are designed to maximize the surface area of the wall between the two fluids, while minimizing resistance to fluid flow through the exchanger. The exchanger's performance can also be affected by the addition of fins or corrugations in one or both directions, which increase surface area and may channel fluid flow or induce turbulence.

A compact heat exchanger can be defined as heat exchanger which has area density greater than 700m2/m3 for gas or greater than 300m2/m3 when operating in liquid or two-phase streams.

The concept behind compact heat exchanger is to decrease size and increase heat load which is the typical feature of modern heat exchanger. The importance of

compact heat exchangers (CHEs) has been appreciated in aerospace, automobile, cryogenics, gas turbine power plant, and other industries for the last 60 years or more. This is due to various factors, for example packaging constraints, sometimes high performance requirements, low cost, and the use of air or gas as one of the fluids in the exchanger.
The other driving factor from last three decades for heat exchanger design has been reducing energy consumption for operation of heat exchangers and minimizing the capital investment in industries. Consequently, in process industries where not-so-compact heat exchangers were mostly common, the use of helical coil-tube heat exchangers and other CHEs has been increasing owing to some of the inherent advantages mentioned above. In addition, CHEs offer the reduction of floor space, decrease in fluid inventory in closed system exchangers, and tighter process control with liquid and phase change working fluids.

Basic Aspects of Compactness

There are basically two types of aspects of compactness. They are:

a) Geometrical aspects:-

The basic parameter describing compactness is the hydraulic diameter dh , defined as

$dh = 4AcL/As$

where, Ac = flow area
and As = surface area

For some types of geometries, the flow area varies with flow length, so for these there is an alternative definition

$dh = 4Vs/As$

where, Vs = enclosed (wetted) volume

Objectives of Work

The objective of the present work is to study the heat transfer characteristics of a helical coil with the variation in curvature ratio (d/D) or Dean Number (De). This analysis has to be done for boundary conditions of both constant wall heat flux and constant wall temperature and also for different flow conditions i.e. laminar flow and turbulent flow. After that comparison of the performance of a helical coil with that of a straight tube has to be done.

II. LITERATURE REVIEW

S.D. Sancheti & DR.P.R .Suresh have worked on the Experimental and CFD estimation of the heat transfer in helically coiled heat exchanger. His work focused on the fluid – to – fluid heat transfer. He validated the basic methodology of CFD analysis in a heat exchanger, without considering actual properties of fluid, a constant value was established instead. For various boundary conditions, the heat transfer characteristics was compared for a helical coil. He found that specification for constant heat flux and constant temperature boundary condition doesn't yield desired modeling for an actual possible heat exchanger. So, heat exchanger was analyzed considering conjugate temperature dependent and heat transfer properties. The fabrication of an experimental set up for the heat transfer characteristics was developed. Experimental results were compared with the results of CFD calculation using CFD package i.e. FLUENT 6.2. Use of constant values for the basic thermal and transport properties in the heat exchanger resulted in prediction of inaccurate heat transfer coefficients. From the results obtained from experiment a correlation was developed for the calculation of inner heat transfer coefficient in a helical coil heat exchanger. [1]
Rahul Kharat, Nitin Bhardwaj and R. S Jha worked on the Development of heat transfer coefficient correlation for concentric helical coil heat exchanger. The existing correlation was found to result in a large discrepancies with increase in the gap between the two concentric coils when they were compared with the experimental results. In their work, CFD simulations and with Fluent 6.3.26 was compared with the experimental data, which was used to develop improved correlation for the heat transfer coefficient. Mathematical model was also developed for analyzing the data, which were obtained from experimental results and CFD to accounts for the effects, by different parameters and functional variables like coil gap, coil diameter and tube diameter. Using numerical technique Optimization was done for the heat transfer coefficient by the new correlation, which fits the experimental data within an error band of 3-4%. [2]

J.S. Jayakumar , S.M Mahajani, J.C Mandal, Kannan N. Iyer and P.K. Vijayan worked on the Thermal hydraulic characteristics of air-water two-phase flows in helical pipes. He worked on the Two fluid Eulerian-Eulerian calculation in Fluent 6.3 for the analysis. The parameters which influence the nature of flow are pitch coil diameter, pitch and diameter in helical coils. CFD analysis was carried out and their variation on thermal and hydraulic characteristics by changing the inlet void fraction for a given flow velocity. The correlations for heat transfer and drop in pressure were analyzed. Estimation of inner heat transfer coefficient by changing the void fraction and flow velocity, results in reduction in 'h' is less below 5% and significant above 15% void fraction [3]

N. Ghorbani, H. Teherain, M. Gorhi and H. Mirgolbabaei worked on the Experimental study of mixed convection of heat exchanger in vertically concentric helical coil heat exchanger. Mixed convection heat transfer in a coil in cell heat exchanger with varying Reynolds no. with varying tube-to-coil diameter ratios and coil pitch were investigated experimentally, for both laminar and turbulent flow. The effects of the coil pitch and diameter of tube on shell-side heat transfer coefficient were studied of the helically coil heat exchanger. Nusselt number correlation with variable coil parameters were analyzed to best fit the data. It is compared with similar studies with specific boundary conditions. It, concluded that, the tube diameter has negligible influence on heat transfer on shell- side, coil surface has –ve effect on h0. The overall heat transfer increases with h0. [4]
Timothy J. Rennie, Vijaya G.S. Raghavan worked on the Numerical studies of a double pipe helical heat exchanger. A double-pipe helical heat exchanger was modeled numerically for numerical flow and the heat transfer characteristics were studied for different fluid flow rates and tube sizes. The overall heat transfer coefficient for both counter and parallel flow were calculated. Simulations were validated by comparing the Nusselt numbers. Greatest thermal resistance were found around the annular region. A correlation was found between the annulus Nusselt no. with a modified dean noumber, which gave a strong linear relationship.[5]

Nomenclature

A_s	**Surface area (m^2)**
A_c	**Cross sectional area of triangular duct (m^2)**
C_p	**Specific heat at constant pressure (J/kg℃)**
AR	**Aspect Ratio**
D_h	**Hydraulic Diameter (m)**
do	**Diameter of orifice (m)**
h	**Average convective heat transfer coefficient (W/m2℃)**
k	**Thermal conductivity (W/m℃)**
L	**Channel length (m)**
$\dot{m}$	**Mass flow rate of air (kg/s)**
Nu	**Nusselt number**
Pr	**Prandtl number**
Re	**Reynolds number**
f	**Friction factor**
Δp	**Pressure drop along length of tube (N/m2)**
T_s	**Average surface temperature (℃)**
T_{bm}	**Bulk mean temperature (℃)**
Ti	**Inlet temperature (℃)**
To	**Outlet temperature (℃)**
QT	**Total heat generated (W)**
Q1	**Actual heat supplied (W)**
Q2	**Heat absorbed by the fluid (W)**
QL	**Heat loss (W)**
V_a	**Velocity of air (m/s)**

Akiyama, M. and Cheng, K.C. worked on the Boundary vorticity method for laminar forced convection heat transfer in curved pipes. Based on their theoretical work he proposed that the Vortex formation and conversion from laminar to turbulent flow occurs due to the secondary flow by the curvature of the helically coil, which produces a centrifugal force and was analyzed by the CFD using Fluent and various correlations were developed. [6]

Dr. Ashok K. Satapathy worked on the Thermodynamic Optimization of a coiled tube heat exchanger under constant wall heat flux condition, based on Fluid – Fluid heat transfer. Optimum diameter ratio of coil, minimizes the degradation of thermal energy and viscous dissipation of mechanical energy. [7]

III. PROBLEM LATION

A helical pipe with 4 turns is taken as the model for the analysis as shown in Fig. 3.1. The coil diameter (D) is taken as 30 mm and total length of the pipe (L) is 3.77 m. The pipe diameter (d) of the model shown in Fig. 3.1 is 10 mm. But, in the analysis four different values of pipe diameter are taken, keeping coil diameter as well as length constant, to see the effect of change in curvature ratio (d/D) on the heat transfer and fluid flow characteristics of a helical pipe. The fluid properties are assumed to be constant.

Fig 3.1 Model of helical pipe

After creating four different geometric models, each model was analyzed for boundary conditions of constant wall temperature and constant wall heat flux and that too for both type of fluid flow conditions i.e. laminar fluid flow and turbulent fluid flow and then results were compared for each case.

Boundary Conditions

The analysis of the model has been done under two sections.

i) Effect of curvature ratio with variable velocity i.e. mass flow rate: The velocities of working fluid assumed at the inlet are 0.6m/s, 0.8m/s, 1m/s, 1.2m/s respectively.

ii) Effect of curvature ratio with variable inlet pressure: Four different gauge pressures are assumed at the inlet. They are 5000 N/m2, 10000 N/m2, 15000 N/m2 and 20000 N/m2.

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From the experimental data at different Reynolds numbers to calculate the different Nusselt number and Friction factor. Equations used for calculation of parameters are listed below.

The mass flow rate of air is calculated by following equation,

$\dot{m} = \rho A_c V_a$

Where ρ is the density of air, A_c is the cross sectional area, V_a is the velocity of air.

In the test section velocity of air is calculated by following equation

$$Va = \frac{m}{\rho Ac}$$

Where ρ is obtained from bulk mean temperature.

The total heat generated by the heater is calculated as,

$Q_T = V_v I$

Where V_v is voltage and I is current,

The actual heat supplied Q_1 is calculated as,

$Q_T = Q_1 + Q_L$

$Q_1 = Q_T - Q_L$

Where heat loss is based on insulation and is obtained by measuring average wall temperature and the ambient temperature.

The heat absorbed by the air is calculated as

$Q_2 = \dot{m} C_p (T_o - T_i)$

The average heat transfer coefficient is calculated as

$Q_1 = h A_s (T_s - T_{bm})$

The average Nusselt number is calculated as

$$Nu = \frac{h\, Di}{k}$$

The friction factor is obtained as

$$f = \frac{\Delta p \; 2D_i}{V2\rho}$$

The Reynolds number is obtained as

$$Re = \frac{\rho V D_i}{\mu}$$

Where μ is dynamic viscosity of fluid.
Prandtl number is given as

$$Pr = \frac{\mu \; C_p}{k}$$

IV. EXPERIMENTAL SETUP

The heat transfer experiments were conducted in an open circular channel / duct and with helical coil. The experimental system consisted of a test section, an entrance section, an outlet section, U-tube manometer, temperature indicator and blower. The test section is 700 mm long and it is insulated with glass wool for avoiding heat transfer outside of channel. The circular channel cross section dimensions is 30 mm. The length of inlet channel is 480 mm long and outlet channel is 250 mm long. The channel was constructed in mild steel material. The inlet section with orifice meter for measuring mass flow rate of air. The 12 numbers thermocouple are used for measuring temperature out of which two thermocouple are used for inlet section and outlet section and remaining ten thermocouple are used for measuring surface temperature. The pressure drop in test section are measured with the help of U-tube manometer. The control panel which consist of ammeter, voltmeter, 12-channel digital temperature indicator.

The experiments are tested with different air flow rates for Reynolds number ranging from 4000 to 22,000. The heat flux is kept constant by adjusting the voltage regulator. During each test the experimental data is recorded after reaching to steady state. After steady state inlet, outlet, surface temperatures, pressure drop across test section and mass flow rate of air are recorded for the calculation of Nusselt number and friction factor.

V.RESULT DISCUSSION

Verification of experimental data of plain channel

The experimental Nusselt number and friction factor characteristics of plain channel are compared and verified. The Nusselt number and friction factor data obtained from current plain channel are validated with those from the proposed correlation by Dittus-Boelter for Nusselt number and correlation by Blasius for friction factor.

These correlations are given below-

Nusselt number correlation of Dittus-Boelter:

$$Nu=0.023\ Re^{0.8}\ Pr^{0.4}$$

Friction Factor correlation of Blasius:

$$f = 0.316\ Re^{0.8}\ Pr^{0.4}$$

The heat transfer characteristics is shown in figure 1.

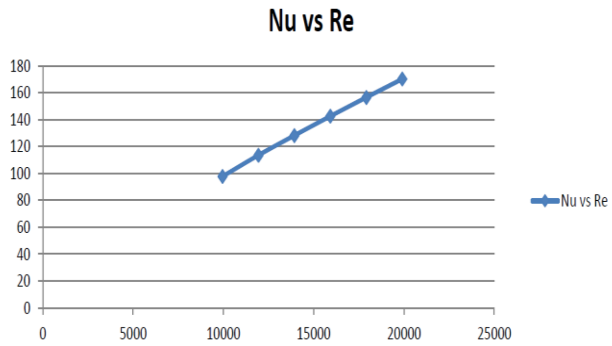

Fig.1 Validation of Nusselt number

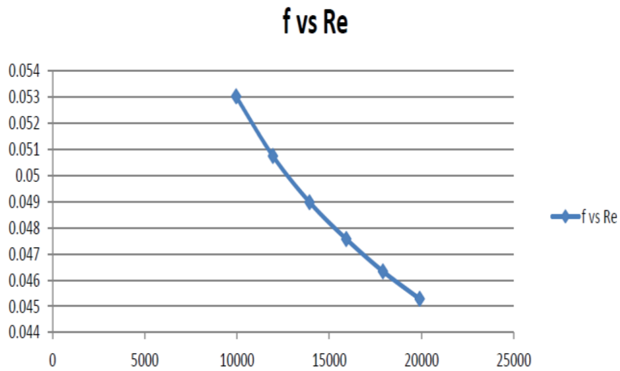

Fig.1 Validation of Friction factor

From above fig. Shows that Nusselt number increases with increase in Reynolds number. & friction factor decrease with increasing Reynolds number.

V.CONCLUSION

The friction factor & nusselt number characteristics are investigated experimentally for smooth tube. The result shown that experimental nusselt number is 20% than the Dittus- Boelter co-relation & friction factor of smooth tube.Friction factor decreases with increase in Reynolds number.By using helical coil in smooth tube turbulence level is increases that is it act as turbulence promoter. Thermal Enhancement factor through out the study is higher than unity indicates significance of Helical coil as insert in plain tube which shows heat transfer is increases as compare to friction factor with minimum pumping loss.

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