International Engineering Research Journal

Experimental Analysis of Shell and coil heat exchanger using Wilson Plot Technique

Gafurama James[1], V.N. Kapatkar[2] and A.B. Korane[3]

[1]Research scholar, Mechanical Engg Dep't, Sinhgad College of Engg, University of Pune, Pune, Maharashtra, India
[2]Prof. Mechanical Engg Dep't, Sinhgad College of Engg, University of Pune, Pune, Maharashtra, India
[3]Assistant Prof. Mechanical Engg Dep't, Sinhgad College of Engg, University of Pune, Pune, Maharashtra, India

Abstract

In the present study, heat transfer coefficient of shell and helically coiled tube heat exchangers analyzedexperimentally. The design and manufacturing of three heat exchangers with different coil pitch and curvature ratio were selected as test section for both parallel and counter flow configuration. All necessary operating parameters of tubes side and shell side were measured using appropriate instruments to find the inner and outer convective heat coefficients using Wilson Plot Technique. Empirical heat transfer and pressure drop correlations were proposed for shell side and tube side. The calculated results were compared with the existing literature and observed reasonable agreement between them.

Keywords: *Helical coil, pitch, Curvature ratio, Counterflow, Flow rate, heat transfer rate and pressure drop.*

1. INTRODUCTION

Heat exchangers are widely used in various applications including power plants, refrigeration and air-conditioning systems nuclear reactors, automotive industries, heat recovery systems, chemical processing, and food industries [1–3]. Besides the performance of the heat exchanger being enhanced, 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 technique requires external forces like fluid vibration and electric heating applications. The passive technique needs special geometries like inserts.Both methods are widely used to improve the performance, refrigeration and air-conditioning system of heat exchangers. Due to their com[pact structure and high heat transfer coefficient, helically coiled tubes are preferred as the best heat exchangers compares to their counterparts in various industrial applications.

Numerous studies indicated that helically coiled tubes are better in providing the best range of heat transfer rate than straight tube heatexchangers. [4,5].

Aheat exchanger is a device that is used to transfer thermal energy (enthalpy) between two or more fluids, between a fluid and a solid surface at different temperature gradients.In heat exchangers, there are different work interactions. Typical applications involve cooling or heating of a fluid stream of concern and evaporation or condensation of single- or multi-component fluid streams. In other applications, the aim may be to recover or reject heat, or sterilize, pasteurize, fractionate, refine, concentrate, crystallize, or control a process fluid.[7]

1.1 Shell and Coil Heat Exchangers

The shell and coil heat exchangers are fabricated using circular layers of helically corrugated tubes placed inside a compact shell. The fluid in each layer flows in the opposite direction to the layer surrounding it, producing a criss-cross pattern. The alternate layers create a swift uniform heatingof the fluids which increasesthe total heat transfer coefficient.

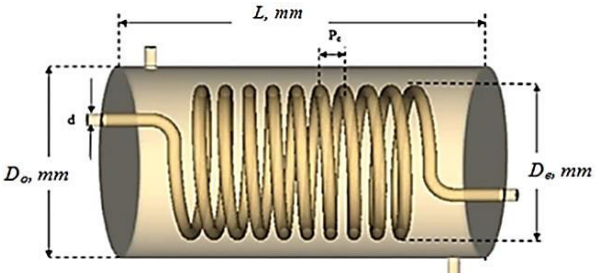

Fig. 1 Schematicdiagram shell and coil heat exchanger

2. Literature Review

T.J. Rennie et.al [1] has done study on the effectiveness 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 for both inner and annulus were calculated and compared to the literature values though boundary conditions were different. The reasonable values were found.

D. G. Prabhanjan et.al [2] has done a study experimentally to determine the 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 the other various studies was the conditions for the helical coil. Mostly, different studies focus on constant wall temperature or constant heat flux, while in this study was a fluid-to-fluid heat exchanger.

In his, M.R. Salimpour [9], experimental study on the heat transfer characteristics of temperature-dependent-property engine-oil inside shell and coiled tube heat exchangers. For this purpose, a well fabricated set-up was designed. Three heat exchangers were selected and tested in the test section for counter-flow configuration. Engine-oil was circulated inside the coil-tube inner whereas coolant water flowing in the shell. All the required parameters like inlet and outlet temperatures of tube-side and shell-side fluids, and flow rate of fluids were using appropriate instruments. An empiricalcorrelation existed in the previous literature for evaluation; the shell-side Nusselt number was invokedto calculate the heat transfer coefficient of the temperature time dependent propertyin the tube side of the heat exchanger. Using the data of the present study, an empirical correlation was developed to predict the heat transfer coefficients.

H. Shokouhmand et.al [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 were calculated using Wilson plots. The inner Nusselt numbers were compared with the existing values in the literature.

Nasser Ghorbani et.al [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 the article was to check the amount of heat transfer rate by changing diameter of the coil, 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 done for the steady-state andthe experiments were conducted for both laminar and turbulent flow inside the 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.

2.1 Problem statement

Under conditions of high temperature applications where long straight tubes may pose severe mechanical problems due to thermal expansion, low flowrates, such that the typical shell-and-tube exchangers have low heat-transfer coefficients and becoming uneconomical, low pressure in one of the fluids, usually from accumulated pressure drops in other process equipment, and when one of the fluids has components in multiple phases (solids, liquids, and gases), which have a tendency to create mechanical difficulties during operations, such as plugging of small-diameter tubes. All these difficulties led to the alternative heat transfer equipment with can work efficiently and minimize most of these problems. Hence shell and coil heat exchanger.

2.2 Objectives

- To study heat transfer coefficients of the shell and helically coiled tube (HCT) heat exchangers.
- To compare the overall heat transfer coefficients of counter-flow and parallel-flow configurations.
- To improvement on the effectiveness of heat exchangers.
- To investigate the heat transfer characteristics in shell and coil heat exchanger, in addition to the pressure drop inside the HCTs.

2.3 Motivation

- Compact size provides a distinct benefit.
- Higher film coefficients—the rate at which heat is transferred through a wall from one fluid to another—and more effective use of available pressure drop result in efficient and less-expensive designs.
- Helical geometry permits handling of high temperatures and extreme temperature differentials without high induced stresses or costly expansion joints.
- High-pressure capability and the ability to fully clean the service-fluid flow area add to the exchanger's advantages.

2.4. Scope of the study

The Significant role of shell and helical coil heat exchanger improves the heat transfer rate. The helical form of coil developed secondary flow pattern and increases the turbulence inside the tube. The effect of pitch ratio (p/d_o) of the coiled tube is affecting onNu_m, and higher value of Nu_m can be achieved with a small value of (p/d_o) while the lower value of Nu_m can be achieved with a high value of p/d_o at the same D/d_o and it will increase heat transfer coefficient as compare to its counterpart straight tube heat exchanger.

3. Experimental Setup

- Preparation of experimental set up with all calibrated equipments.
- Set a procedure to test the given parameters.
- Apply those parameters as a boundary condition for helical coil
- Comparison will be made between existing and present work.
- Specify future scope of the research work.
- Conclusion of thermal and pressure drop performance

3.1 Comparison

- To compare present data with existing literature for double pipe helical coil heat exchanger.
- To observe effect of pitch ratio on heat transfer and pressure drop performance.
- To compare heat transfer rate and pressure drop performance of straight tube (shell-and-tube) heat exchanger and coiled tube (heat helical coil) heat exchanger.

3.2 Geometry of shell and coiled tube heat exchanger

Geometry of coiled tube heat exchanger is shown in Fig.4.1 in this figure, $d$is the diameter of the coiled tube; $p$is the coil pitch; $R$is the curvature radius of the coil. The curvature$\phi$is defined as the coil to tube diameter ratio, $d/2R$.The schematic diagram of the experimental setup is shown in the Figure 2. The setup is a well instrumented single-phase heat exchanging system in which the shell side and vice-versa

Operating Parameter and Dimension

Table 1: Characteristic dimensions of shell and coiled tube heat exchangers

No.	d_i, mm	d_o, mm	D, mm	p, mm	δ	L, mm
1	8	10	210	0,10,15	0.0476	4000
2	10	12	210	0,10,15	0.0571	4000
3	12	14	210	0,10,15	0.0666	4000

Table 2: Range of parameters with pre-assumed corresponding values*

Parameters	Range
Tube side water flow rate	0.003–0.024 kg/s
Shell side water flow rate	0.004–0.025 kg/s
Tube inlet temperature	55–60 °C
Tube outlet temperature	42–50 °C
Shell inlet temperature	35–37 °C
Shell outlet temperature	49–44 °C

Table 3: Experimental readings for both shell and coil sides

Tube side inlet temp. (°C)	Shell side inlet temp. (°C)	Tube side water flow (LPH)	Shell side water flow (LPH)
30	55	15, 30, 45, 60, 75,90,105,120	15
30	55	15, 30, 45, 60, 75,90,105,120	30
30	55	15, 30, 45, 60, 75,90,105,120	45
30	55	15, 30, 45, 60, 75,90,105,120	60
30	55	15, 30, 45, 60, 75,90,105,120	70

Table 4: Geometric specifications of coiled tube

Coil	PCD (mm)	Pitch (mm)	Tube diameter (mm)	No. of active turns
Coil 1	214	0, 10, 15	6/8	5.5
Coil 2	218	0, 10, 15	8/10	5.5
Coil 3	222	0, 10, 15	10/12	5.5

Table 5: Geometric specification of shell

Length of the shell (mm)	Diameter of the shell	Thickness (mm)	Material
280	240	2	Stainless Steel

3.3 Material and Method

Three heat exchangers are to be constructed from copper tubing and standard brass connections. The copper tubes are 4m long, 6mm, 8mm, and 10mm inner diameters and 8mm, 10mm, and 12mm outer diameters coils. The circular coil had a curvature radius 105 mm from tube center. The coil of 5.5 number of active turns will be made on wooden pattern. When the bending of copper tube very fine sand filled in tube to maintain smoothness on inner surface and this washed with compressed air. The care has to be taken to preserve the circular cross-section of the coil during the bending process. The end connections joined at copper tube ends and two ends drawn from coiled tube at one position.

3.4 Experimental Apparatus

The performed was taken on the set-up show in Fig. 2. The hot water tank with capacity of 3000Watts thermostatic electric heater was used to supply the constant hot water temperature on outer shell side.The hot water pump with 0.125kW capacity was used.The cold water used flowing in the helically coiled tube.

The two flow-meters were put to measure mass flow rate for both hot water and cold water Flexible PVC tubing was used and K type thermocouples are inserted in both brass and copper connectors to measure inlet and outlet temperatures of both the fluids. Temperature data will be recorded using data acquisition/switch unit.

3.5 Experimental set up

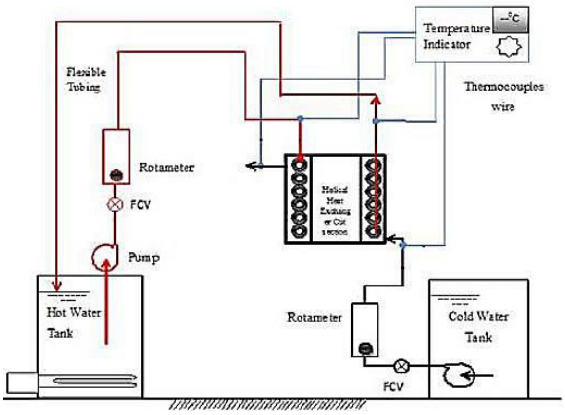

Fig. 4 Experimental Setup of Helical coil heat exchanger

3.6 Test Procedure

The set-up instrumented single phase heat exchanger system. The main component of the set-up is coiled heat exchangers, Centrifugal pump, hot water tank, Cold water tank. From the hot water tank of constant temperature, 60 °C, water supply in tube side, the mass flow rate varies from 0.003–0.024 kg/s. Cold water supply, in shell side with mass flow rate 0.004–0.025 kg/s. Flow rate of hot water and cold water is to be controlled by ball valve. After reaching set temperature, pump is to be started and starts to circulate hot water from tube side. The temperature data will be recorded for every 5 min. This data will be taken after temperature is stabilized.

The input-output temperature of flowing fluid measured with varying mass flow rate in tube and shell side. From K-type thermocouples will be used to determine temperature limits errors. All the pipes, shells and pipe near end connection (came in contact with surrounding) insulated. The tube side pressure drop measured with appropriate pressure indictor. The dimensions of the heat exchangers are pre-assumed in Table 1.

4. Data Collection and analysis

In present investigation work the heat transfer coefficient and heat transfer rates will be determined based on the measured temperature data. The heat will be flowing from tube side hot water to shell side cold water. The operating parameter range is given in Table 2.

Tube Side Heat transfer

$$Q = m_t Cp_t (t_{in} - t_{out}) \quad (1)$$

Shell Side Heat Transfer

$$Q = m_s Cp_s (t_{in} - t_{out}) \quad (2)$$

The physical properties of taken on average temperature

$$T_m = (T_{in} - T_{out})/2 \quad (3)$$

The heat transfer coefficient was calculated with,

$$U_o \equiv \frac{Q}{A_o \Delta T_{LMTD}} \quad (4)$$

The overall heat transfer surface area was determined based on the tube diameter and developed area of tube diameter. $A_{total} \equiv \pi L d$.

LMTD is the log mean temperature difference, based on the inlet temperature difference $\Delta T1$ and outlet temperature difference $\Delta T2$,

$$\Delta T_{LMTD} \equiv \frac{\Delta T2 - \Delta T1}{ln(\Delta T2/\Delta T1)} \quad (5)$$

The flow rate in shell side was varying with combination to tube side flow rate. The overall heat transfer coefficient can be related to the inner and outer heat transfer coefficient from following equation,

$$\frac{1}{U_0} = \frac{A_o}{A_i h_i} + \frac{A_0 \ln(d_o/d_i)}{2\pi K L} + \frac{1}{h_o} \quad (6)$$

where d_i and d_o are inner and outer diameters of the tube respectively, K is the thermal conductivity of the wall material and L, length of the stretched.

4.1 Methodology: Wilson plot technique

The Wilson plot method was developed by Wilson in1915 to evaluate the convection coefficients in the shell and tube condensers for the case of a vapour condensing outside by means of a cool liquid flow inside. It is based on the separating the overall thermal resistance into the inside convective thermal resistance and the remaining thermal resistances participating in the heat transfer process.

The internal convection (R_i), the tube wall (R_w) and the external convection (R_o), as shown in Equation below.

$$R_{ov} = R_i + R_w + R_o \quad (7)$$

The overall thermal resistance can be rewritten as Eq.

$$R_{ov} = \frac{1}{h_i \cdot A_i} + \frac{\ln(d_o/d_i)}{2 \cdot \pi \cdot k_w \cdot L_w} + \frac{1}{h_o \cdot A_o} \quad (8)$$

The overall thermal resistance can be conceived as a function of the overall heat transfer coefficient referred to the inner or outer tube surfaces and the corresponding areas.

The overall heat transfer coefficient referred to the inner or outer surface (Ui/o) and the inner or outer surface area (Ai/o).

Wilson [1] hypothesized that if the mass flow of the cooling liquid was modified, then the change in the overall thermal resistance would be mainly due to the variation of the in-tube convection coefficient, while the remaining thermal resistances remained nearly constant.

$$R_w + R_0 = C_1 \quad (9)$$

Wilson determined for the case of fully developed turbulent liquid flow inside the circular shell, the convection was proportional to the power reduced (Vr) which accounts for the property of variation of the fluid and the tube diameter. Thus, the convection coefficient could be written according to equation below.

$$h_i = C_2 . V_r^n \quad (10)$$

where C_2 is a constant, v_r is the reduced fluid velocity and n is a velocity exponent.

Combining Eqn. (7) to (10), the resulting equation would be obtained as equation of straight line and plotted as shown below:

$$R_{ov} = \frac{1}{C_2 \cdot A_i} \cdot \frac{1}{v_r^n} + C_1 \quad (11)$$

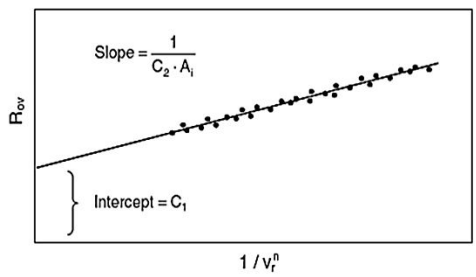

Fig. 2 Original Wilson plot technique

5. Result and Discussion

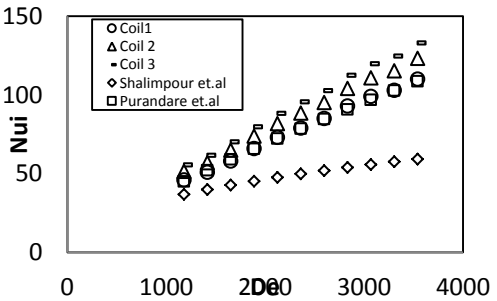

Fig. 3 Variation of tube side Nusselt number with its dean number

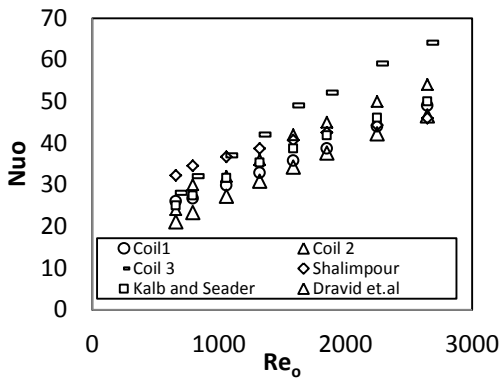

Fig.4 Variation of shell side Nusselt number with its Reynolds number

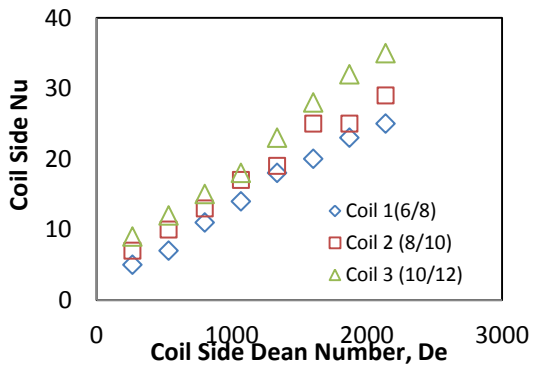

Fig. 5 Variation of tube side Nusselt number with its dean number for 10 mm pitch

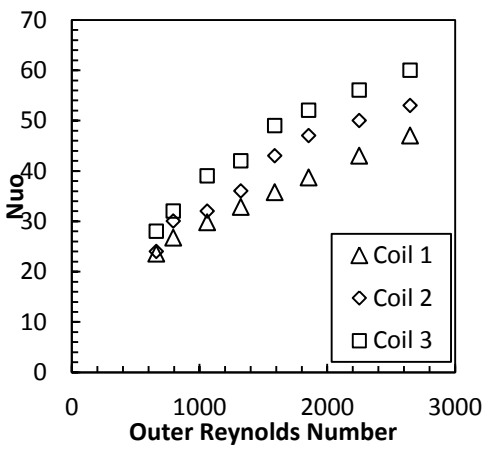

Fig. 6 Variation of shell side Nusselt number with its Reynolds number for zero pitch size.

Fig. 3 presents the variation of inner Nusselt number with tube side dean number. The obtained experimental results were compared with the existing literature and found that Purandare et.al correlation of helical coil was fit with experimental data with 10 % variation. Coil 3 shows good result compared to the other coils. Its surface area of coil 3 is larger than the other coil.

Fig. 4 presents the shell side Nusselt number increases with increase in shell side Reynolds number. Salimpour et.al, Kalb and Seader et.al and Dravid et.al data strongly matches with the experimental work.

Fig. 5 shows that the coil side Nusselt number increases as the Dean number is increased and the Coil 3 shows better results than other remaining two coils. Coil 3 shows good results due to its larger surface area compared to other coils. The increase in the Nusselt number gives a better heat transfer rate.

Fig. 6presents the variation between Nusseltnumber of the shell with its Reynolds number for zero pitch. Increase in velocity of the flow increases Nusselt number but the increases should not exceed the laminar flow region for the best results.

6. Conclusion

An experimental study of helical tube heat exchanger was performed by using three heat exchangers with different coil pitch and curvature ratio were selected as test section for both parallel and counter flow configuration. The heat transfer rate is strongly dependent of curvature and pitch of the coils. It is assumed that the empirical correlations for helical coiled heat exchanger are quite in agreement with the present experimental data.

The effect of pitch ratio (p/d_o) of the coiled tube is affecting onNu_m, and higher value of Nu_m can be achieved with a small value of (p/d_o) while the lower value of Nu_m can be achieved with a high value of p/d_o at the same D/d_o and it will increase heat transfer coefficient as compare to its counterpart straight (Shell-and-tube) heat exchanger.

Acknowledgement

Authors would like to thank the college authority and all those who directly or indirectly contributed to our work.

Reference

[1] Timothy J. Rennie, VijayaG.S..Raghavan, *2005 Experimental studies of a double-helical pipe heat exchanger*.

[2] D.G. Prabhanjan, G.S.V. Raghavan, T.J. Rennie, *Comparison between heat transfer rates of straight tube and helically coiled tube heat exchangers*

[3] H. Shokouhmand, M.R. Salimpour, M.A. Akhavan-Behabadi, *2007 Experimental investigation of shell and coiled tube heat exchangers using Wilson plots*.

[4] N. Ghorbani, H. Taherian, M. Gorji, H. Mirgolbabaei, 2009, *Experimental study of mixed convection heat transfer in vertical helically coiled tube heat exchangers*.

[5] Chang-Nian Chen, Ji-Tian Han, Tien-Chien Jen, Li Shao , Wen-wen Chen, 2010, *Experimental study on critical heat flux characteristics of R134a flow*

boiling in horizontal helically-coiled tubes.

[6] J.S. Jayakumar, S.M. Mahajani, J.C. Mandal, P.K. Vijayan, RohidasBhoi, *Experimental and CFD estimation of heat transfer in helically coiled heat exchangers*.

[7] Nasser Ghorbani, HessamTaherian, MofidGorji, HessamMirgolbabaei, 2010, *An experimental study of thermal performance of shell-and-coil heat exchangers*

[8] PaisarnNaphon, SomchaiWongwises, 2004, *A study of the heat transfer characteristics of a compact spiral coil heat exchanger under wet-surface conditions*.

[9] M.R.,Salimpour, 2008,*Heat transfer of a temperature-dependent property for shell and tube heat exchanger.*

[10] M.R. Salimpour,2008, *Heat transfer coefficients of shell and coil heat exchanger.*

[11] PairsanNaphon, *Study on heat transfer in Spiral coiled heat exchanger.*

[12] Rahul Kharat, NitinBhardwaj, R.S. Jha, 2009, *Development of heat transfer coefficient correlation for concentric helical coil heat exchanger.*