DESIGN AND EXPERIMENTAL ANALYSIS OF SPIRAL TUBE HEAT EXCHANGER

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Abstract— Spiral tube heat exchangers are known as excellent heat exchanger because of far compact and high heat transfer efficiency. An innovative spiral tube heat exchanger is designed for particular process engineering. A new arrangement for flow of hot and cold fluids is employed for design, hot fluid flows in axial path while the cold fluid flows in a spiral path. To measure the performance of the spiral tube heat exchanger, its model is suitably designed and fabricated so as to perform experimental tests. The paper gives analysis of spiral tube heat exchanger over the shell and tube heat exchanger.

Key words — spiral tube heat exchanger.

I. INTRODUCTION

1.1) Heat Exchanger

One of the important processes in engineering is the heat exchange. The means of heat exchanger that to transfer the heat between flowing fluids. A heat exchanger is the process to transfer heat from one fluid to another fluid. The heat exchanger is devise that used for transfer of internal thermal energy between two or more fluids at different temperatures. In most heat exchangers, the fluids are separated by a heat transfer surface, and ideally they do not mix. Heat exchangers are used in the process, power, petroleum, transportation, air conditioning, refrigeration, Cryogenic, heat recovery, alternate fuels, and other industries. Common examples of heat exchangers familiar to us in day-to-day use are automobile radiators, condensers, evaporators, and oil coolers. Heat exchangers could be classified in many different ways.

1.2) Classification Of Heat Exchangers

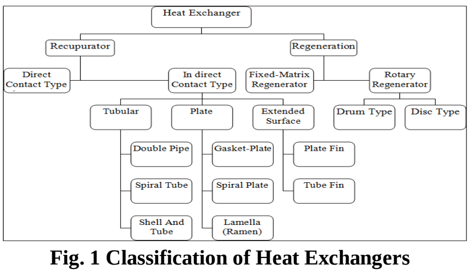

Fig. 1 Classification of Heat Exchangers

1.3) Tubular Heat Exchanger

Tubular heat exchangers are generally built of circular tubes ,although elliptical, rectangular or round/flat twisted tubes have also been used in some applications. There is considerable flexibility in design because the core geometry can be varied easily by changing the tube diameter, length, and arrangement. Tubular exchangers can be designed for high pressures relative to environment and high pressure differences between the fluids.

Tubular exchangers are used primarily for liquid to liquid and liquid to phase change (condensing or evaporating) heat transfer applications. There are also used for gas to liquid and gas to gas heat transfer applications primarily when the operating temperature and pressure is very high or fouling is a severe problem on at least one fluid side and no other types of exchangers work. These tubular exchangers may be classified as shell-and-tube, double-pipe, and spiral tube heat exchangers. There are all prime surface exchangers except for exchangers having fins.

1.3.1) Double Pipe Heat Exchanger

A typical double pipe heat exchanger consists of one pipe placed concentrically in side another of larger diameter with appropriate fittings to direct the flow from one section to the another section. One fluid flows through the inner pipe and other fluid flows through the annular space. Double-pipe heat exchangers can be arranged in various series and parallel arrangements to meet pressure drop and mean temperature difference requirements. The major use of double pipes exchangers for sensible heating or cooling of process fluids where small heat transfer area required. This configuration is also very suitable for one or both fluids are at high pressure because of the smaller diameter of the pipe. The major disadvantage is that double-pipe heat exchangers are bulky and expensive per unit transfer surface. Inner tube being may be single tube or multi-tubes. If heat transfer coefficient is poor in annulus, axially finned inner tube can be used. Double-pipe heat exchangers are built in modular concept, i.e., in the form of hairpins.

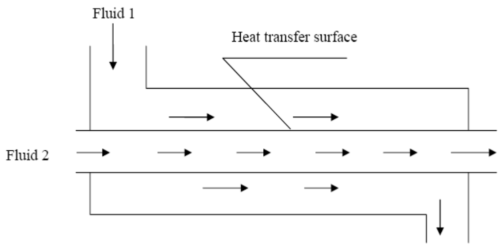

Fig. 2 Double Pipe Heat Exchanger

1.3.2) Shell And Tube Heat Exchanger

Shell and tube heat exchangers are built of round tubes mounted in large cylindrical shells with the tube axis parallel to that of the shell. These are commonly used as oil coolers, power condensers, pre-heaters and steam generators in both fossil fuel and nuclear-based energy production applications. They are also widely used in process applications and in the air conditioning and refrigeration industry. Although they are not specially compact, their robustness and shape make them well suited for high pressure operations. They have larger heat transfer surface area to volume ratio than the most of common types of heat exchangers, and they are manufactured easily for a large variety of sizes and flow configurations.

They can operate at high pressures and their construction facilitates disassembly for periodic maintenance and cleaning. The shell-and-tube heat exchangers consist of a bundle of tubes enclosed within a cylindrical shell. One fluid flows through the tubes while the second fluid flows space between the tubes and shell. In shell and tube heat exchanger, the shell side stream flows across between pairs of baffled, and then flows parallel to the tube. There are wide differences between shell-and-tube heat exchangers depending on the application. The main design objectives here are to accommodate thermal expansion, to furnish ease of cleaning, or to provide the least expensive construction.

A number of shell side and tube side flow arrangement are used in shell and tube heat exchangers depending on heat duty, pressure drop, pressure level, fouling, manufacturing technique and cost, corrosion control, and cleaning problem. The baffles are used in shell and tube heat exchanger to promote better heat transfer coefficient on the shell side and to support the tubes.

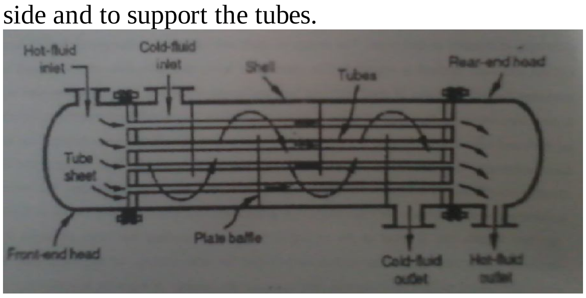

Fig. 3 Shell And Tube Heat Exchanger

1.3.3) Spiral Tube Heat Exchanger

Spiral tube heat exchanger has excellent heat exchanger because of far compact and high heat transfer efficiency. Spiral-tube heat exchangers consist of one or more spirally wound coils which are, in circular pattern, connected to header from which fluid is flowed. This spiral coil is installed in a shell another fluid is circulated around outside of the tube, leads to transfer the heat between the two fluids.

Heat transfer rate associated with a spiral tube is higher than that for a straight tube. In addition, a considerable amount of surface can be accommodating in a given space by spiralling. In spiral tube heat exchanger, problem of thermal expansion is not probably occurring and self cleaning is also possible. A spiral tube heat exchanger is a coil assembly fitted in a compact shell that to optimizes heat transfer efficiency and space. Every spiral coil assembly has welded tube to manifold joints and uses stainless steel as a minimum material requirement for durability and strength.

Spiral tube heat exchanger uses multiple parallel tubes connected to pipe or header to create a tube side flow. The spaces or gaps between the coils of the spiral tube bundle become the shell side flow path when the bundle is placed in the shell. Tube side and shell side connections on the bottom or top of the assembly allow for different flow path configurations. The spiral shape of the flow for the tube side and shell side fluids create centrifugal force and secondary circulating flow that enhances the heat transfer on both sides in a true counter flow arrangement. Since there are no baffles are provided in to the system, therefore to lower velocities and heat transfer-coefficients. performance is optimized. Additionally, since there are a variety of multiple parallel tube configurations are not compromised by limited shell diameter sizes as it is in shell and tube designs. The profile of a spiral is very compact and fits in a smaller path than a shell and tube design. Since the tube bundle is coiled, space requirements for tube bundle removal are almost eliminated.

When exotic material is required, a spiral tube heat exchanger minimizes the material used since manifolds replace the channels, heads and tube sheets of a conventional shell and tube design. Spiral tube heat exchanger uses single channel technology, which means that both fluids occupy a single channel, which allows fully counter-current flow. One fluid (hot fluid) enters the centre of the unit and flows towards the periphery. The other fluid (cold fluid) enters the unit at the periphery and moves towards the centre. The channels are curved and have a uniform cross section, which creates “spiralling” motion within the fluid. The fluid is fully turbulent at much lower velocity than straight tube heat exchangers, and fluid travels at constant velocity throughout the whole unit.

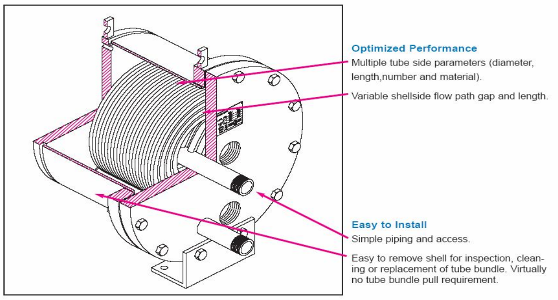

Fig. 4 Spiral Tube Heat Exchanger

Spiral tube heat exchanger consists of number of spirals attached to the header. One fluid flows from periphery to center of the casing while the other is moving from center to periphery, it has following advantages,

1 Because of the spiral flow paths imparted to the tube- and shell-side fluids, the effects of centrifugal force and secondary circulating flow enhance heat transfer on both sides in a counter flow arrangement.

2 The other fluid enters the unit at the periphery and moves towards the centre. The channels are curved and have a uniform cross section, which creates "spiraling" motion within the fluid.

3 The fluid is fully turbulent at a much lower velocity than in straight tube heat exchangers, and fluid travels at constant velocity throughout the whole unit, and thus the sticking of oil problem will be eliminated.

4 Spiral heat exchangers require small area for mounting resulting in lower unit installation cost compared with other.

5 Compared with other types of heat exchanger, spiral unit provides the best access to their heat transfer area with no special tools or lifting equipment required.

Disadvantage of spiral tube heat exchanger is that the Designs are proprietary – limited number of manufacturers.

Features of spiral tube heat exchanger are describe below,

Optimal design for corrosive fluid, High flow in a small path, Highly resistant to thermal and hydraulic shock, Bolted or all welded shell, Numerous flow path and connection configurations, Compact and lightweight, easy to install

II. LITERATURE REVIEW

2.1) G. E. KONDHALKAR & V. N. KAPATKAT [1] Gives the performance analysis of spiral tube heat exchanger over the shell and tube type heat exchanger. They found that the cost saving using spiral tube heat exchanger is around 15 –20 % as compared to shell and tube type heat exchanger and to establish that improvement in overall heat transfer coefficient as compared to shell and tube type heat exchanger from 400 to 650W/m2K. The process at higher velocity was not suitable. So it is decided to keep the low velocity with more turbulence which is reduced fouling and increases the heat transfer rate as well as oil will not stick to the inner surface of the tubes.

2.2) J.P. HARTNETT & W.J. MINKOWYCZ [2] They are investigate the average in tube heat transfer co-efficient in spiral coil heat exchanger. The test section is spiral coil heat exchanger which consists of six layer of concentric spiral coil tube. They obtain the experiment result of tube heat transfer coefficient in spiral coil heat exchanger under dehumidifying conditions. They give the experimental equation and compare with the present correlation and to obtain new correlation.

2.3) P. Naphon [3] proposed that the heat exchanger consists of a shell and helically coiled tube unit with two different coil diameters. Cold and hot water are used as working fluids in shell side and tube side. The cold and hot water mass flow rates ranging between 0.10 and 0.22 kg/s, and between 0.02 and 0.12 kg/s. He conclude that Outlet cold water temperature increases with increasing hot water mass flow rate. An average heat transfer rate increases as hot and cold water mass flow rates increase. The friction factor decreases with increasing hot water mass flow rate. Inlet hot and cold water mass flow rates and inlet hot water temperature have significant effect on the heat exchanger effectiveness.

2.4) Yan Ke, G. P.Qi, Et Al. [6] They had analyze transverse vibration of conical spiral tube bundle. The effect of the external fluid flow on the transverse vibration of tube bundle is studied with the combination of experimental data, empirical correlations and FEM. The external fluid flow has a significant effect on the frequency of the tube's transverse vibration, which are decreased by about 18% to 24% when the external fluid flow speed is 0.3 m/s.

2.5) P. M. DESHPANDE & DR. S. DAWANDE [4] studied horizontal spiral coil tube (HSTC) for various forces (viscous, buoyancy and centrifugal force) acting on fluid element in coil; of which the centrifugal force is predominant and results in secondary flow. This phenomenon also depends on the physical properties of fluid at a given temperature. They also concluded that as the coil diameter reduces the curvature ratio increase that increases the pressure drop.

2.6) DR. M. S. TANDALE & S. M. JOSHI [5] provided analytical model to design of spiral tube heat exchanger and experiments were performed. The experimental results show that the deviation between calculated values of overall heat transfer coefficient from the experimental results and theoretical values obtained from the analytical model are within 12%. Also, the accuracy is found to be within ±8 % in approximation. The pressure drop estimated is also compared with actual values observed during experimentation, which is found in acceptable range.

2.7) R. K. PATIL, & B.W. SHENDE Et Al. [8] proposed that heat transfer rate of helical coil heat exchanger is better to compare another types of heat exchanger. In the helical coil heat exchanger space is limited so not enough straight pipes should be laid. The helical tube heat exchangers consist of helical coil fabricated out metal pipe that is fitted in the annular portion of two concentric cylinders.

2.8) M. P. Nunez, & G. T. Polley [7] present method for the sizing of spiral plate heat exchangers. From this method given physical dimensions like width, thickness to achieve pressure drop and heat duty meet the required specifications of the design. The temperature profiles of the exchanger calculated analytically show the same tendency as those obtained numerically. The major simplification involved in the derivation of this method is the use of empirical correlations that do not account for the variation of the heat transfer coefficient with the curvature and do not consider the entry length effects.

2.9) A.M. Fuentes & L.C. Davalos Et Al. [9] present an alternative design approach for the sizing of spiral heat exchangers in single phase counter-current applications. The pressure due to friction can be directly related to the heat transfer coefficient through the exchanger geometry, thus resulting in a sizing methodology that maximises pressure drop and results in the design of the smallest dimensions. This type of exchanger gives less heat transfer area compared to shell and tube exchangers which, in some cases, has some advantages in terms of weight, volume and cost.

2.10) M. P.Nueza ,& G.T. Polley [10] provides the design space where the available options that meet the heat duty and allowable pressure drops are displayed for the various geometrical parameters. the design space is determined considering standard exchanger by a set of set of three curves: a curve that represents the heat duty (thermal length) and two curves that represent the pressure drop on the hot and cold streams. They conclude that the graphical representation of the design parameters that fulfil the process heat load and pressure drops. They refer to the selection of the exchanger dimensions that will meet the heat duty within the limitations of pressure drop and the space between the streams is same.

III. DESIGN METHODOLOGY

The amount of heat transfer rate or heat potential is calculated by using following energy balance equations,

$$Q_h = m_h \times c_{ph} \times T_{h1} - T_{h2}) \quad (1)$$

Following data is adopted for design of spiral tube heat exchanger which is describe below,

Inner temperature of hot side (T_{h1})	: 70 °C
Inner temperature of cold side (T_{c1})	: 31.3 °C
Outer temperature of hot side (T_{h2})	: 52 °C
Outer temperature of cold side (T_{c2})	: 38 °C
Tube outer diameter (d_o)	: 12 mm
Tube inner diameter (d_i)	:10 mm
Channel width (H)	: 30 mm
Thickness of outer tube	:0.065 mm
Tube spacing (b)	: 10 mm
Thickness of inner tube	: 0.049 mm
No. Of spiral	: 04
Pitch (p)	: 24 mm

Nomenclature

A_r	heat transfer area (m^2)
T_{h1}	Inlet temperature of hot fluid (°c)
A_w	heat transfer area for tube side (m^2)
T_{h2}	Outlet temperature of hot fluid (°c)
A_s	Area for shell side (m^2)
U	Overall heat transfer coefficient ($w/m^2 \times °c$)
a	Constant in equation of spiral
V_o	Velocity of fluid (m / s)
C_{ph}	Specific heat of hot fluid (kj / kg ×k)
C_{pc}	Specific heat of cold fluid (kj / kg ×k)
D_e	Equivalent diameter (mm)
D_i	Inner diameter of tube (mm)
D_o	Outer diameter of tube (mm)
D_{ho}	Header outer diameter (mm)
d_s	Channel space (mm)
D_i	Inner diameter of shell (mm)
H	Tube width (mm)
L	Length of shell (m)
m_h	Mass flow rate of the hot fluid (m / s)
m_c	Mass flow rate of the cold fluid (m / s)

Dimensionless numbers

N_u	Nusselt number
P_r	Prandtl number
R_e	Reynolds number
R_{ec}	Critical Reynold number

Greek symbol

Δp	Pressure drop (p_a)
N	No. of spiral
μ	Viscosity of fluid (kg /m × s)
p	Tube pitch (mm)
ΔT_{lm}	Log mean temperature different (°c)
Q_c	Heat transfer rate of cold side (kw)
K	Thermal conductivity (w/ m × °c)
Q_h	Heat transfer rate of hot side (kw)
ρ	Density of fluid (kg / m^3)
R_o	Outer radius of spiral (mm)
h	Heat transfer coefficient (w/ m ^{2}× °c)
R_i	Inner radius of spiral (mm)
T_{c1}	Inlet temperature of cold fluid (°c)
T_{c2}	Outlet temperature of cold fluid (°c)

Flow arrangement selected is counter flow type and accordingly LMTD for this stage is calculated.

$$\Delta T_{lm}=(T_{h1}-T_{c2})-(T_{h2}-T_{c1})/\ln(T_{h1}-T_{c2})/(T_{h2}-T_{c1}) \quad (2)$$

There are many methods to calculate the shell inside diameter. Therefore following one is the formula for finding the shell inside diameter. The value of R_o is found out using equation (7) and shell diameter is calculated using equation (8)

$$L=1/2a\times (R_o^2 - R_i^2) \quad (3)$$

From above equation, $a = p / 2 \times \Pi$, $p = 2 \times d_o$,

$$D_i=(R_o + d_{ho}) \times 2 \quad (4)$$

Further, shell side film heat transfer coefficient is calculated using equations (9).

$$A_{shell}=\Pi/4\times D_i^2-[(L\times d_o)+\Pi/2\times(d_{ho})^2] \quad (5)$$

$$V_s = m_s / \rho_s \times A_s \quad (6)$$

$$R_e=\rho_s\times V_s \times D_o / \mu \quad (7)$$

Using Grimson's Correlation for Nusselt number for flow across bank of the tubes,

$$N_{shell}=1.13\times C_1\times(R_e)^{0.6}\times(P_r)^{0.3} \quad (8)$$

The heat transfer coefficient is achieve from to obtain Nusselt number,

$$h = N_u \times k / d_o \quad (9)$$

Calculate the Critical Reynolds number R_{ec}. The R_{ec} is the critical Reynolds number is the value of Reynolds number above which turbulence flow is achieved,

$$R_{ec}=20{,}000\times (D_e / D_o)^{0.32} \quad (10)$$

For equivalent diameter,

$$D_e = 4 \times A_c / P_h \quad \text{Here, } A_c = \Pi (D_i^2 - d_o^2) / 4 \text{ and } P_h= \Pi \times d_o \quad (11)$$

The water side heat transfer coefficient is calculated using equations,

$$A_w=\Pi/4\times d_i^2\times N \quad (12)$$

$$V_w=m_w / \rho_w \times A_w \quad (13)$$

From Reynolds number tube side,

$$R_e=\rho_w\times V_w \times d_i /\mu_w \quad (14)$$

Using Gnielinski's Correlation for Nusselt Number,

$$N_u=0.296\times R_e^{0.63}\times P_r^{0.3}\times P_t^{0.25}\times\mu_v^{0.14} \quad (15)$$

Here, $P_t =R_o^{1.92}-R_i^{1.92}/P \times d_i^{0.92}$, and $\mu_v = \mu_b/\mu_w$

Heat transfer coefficient for tube side,

$$h_w = N_u \times k / d_i \quad (16)$$

The overall heat transfer coefficient,

$$1/ U = 1 / 1 / h_i + d_o / 2K \times \ln d_o / d_i + 1 / d_o \times d_o/d_i \quad (17)$$

Calculate heat transfer area required by overall heat transfer coefficient,

$$A_r=Q/ U \times \Delta T_{lm} \quad (18)$$

For pressure drop , $R_e < R_{ec}$

$$\Delta p = 36.84 \times L/\rho \times [w/d_s \times H] \times [1.035 \times \mu^{0.5} / (d_s+ 0.032) \times (H/w)^{0.5} \times (\mu_f/\mu_b) + 1.5 + 16/L] \quad (19)$$

CONCLUSION

It can be concluded that design methodology available in literature is in scattered manner. The previous works carried out by different authors were limited to helical coil heat exchanger and spiral plate heat exchanger. The spiral tube heat exchanger is compact in size and more heat transfer can be carried out.

The objective of present work is to streamline design methodology of spiral tube heat exchanger. The designed spiral tube heat exchanger is required to be developed and experiments will be performed on it to analyses pressure drop and temperature change in hot and cold fluid on shell side and tube side.

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