DESIGNING OF A PROFICIENT HEAT EXCHANGER BY USING SPIRAL TUBE FOR AUGMENTATION OF HEAT TRANSFER

Prof. G. N. Deshpande

Assistant Professor in Mechanical Engineering Department,

Shreeyash College of Engineering & Technology, Aurangabad, Maharashtra

deshpande.gaurav9@gmail.com

Abstract

Heat exchangers are the equipment that exchanges the heat energy between the surface and the fluid. Heat exchangers are used in both day to day life and in industrial applications such as thermal power plant, chemical plant, HVAC, automobiles as radiators. Most of the heat exchangers design depends upon the requirement and space. Depending on the exchanger design methodology, there are a set of geometrical parameters that need to be specified before the start of design. Hence proficient design of heat exchanger is always needed one of them is spiral tube heat exchanger. The present design procedure is different from that of the design procedure of tubular heat exchanger. Archimedean principle of spiral geometry is used while designing the spiral coils for spiral tube heat exchanger. The design of the heat exchanger consists of the specification of the geometry (cross sectional area and length) that transfers the required heat load within the limitations of allowable pressure drop.

Keywords: Spiral Tube Heat Exchanger, LMTD, curvature ratio, effectiveness of HE etc.

Nomenclature

List of symbols

d - Diameter of spiral tube [mm]

D_{is} -Diameter of shell [mm]

P- Pitch of Spiral[mm]

L_{st}- Length of header tube [mm]

B- Bend allowances [mm]

L_T - Total length of spiral tubes [mm]

k- Stretch factor or bend factor

n- Number of spiral

Q- Heat transfer rate of fluid [W]

T_{h1}- Inlet temperature of hot fluid [ºC]

T_{c1}- Inlet temperature of cold fluid [ºC]

ΔP- Pressure drop [mm]

D- Diameter of Spiral [mm]

R_h- Radius of header or Straight tube [mm]

L_s- Length of shell[mm]

a- Constant in equation of Spiral [mm]

L_o- Developed length of spiral [mm]

r_n- Neutral axis correction radius [mm]

t- Thickness of tube [mm]

n_1- Number of header tube

C_P- Specific heat [KJ/kg k]

T_{h2}- Outlet temperature of hot fluid[ºC]

T_{c2}- Outlet temperature of cold fluid [ºC]

U- Overall Heat transfer coefficient [W/m^2K] h- Heat transfer coefficient [W/m^2K]

A_s- Heat transfer surface area [m^2]

R- Capacity ratio

m- mass flow rate of fluid [kg/s]

V- Velocity of fluid [m/s]

R_s- Thermal resistance of spiral tube

R_{st}- Thermal resistance of header tube

m_{np}- mass of nanoparticle [g]

m_{bf} – mass of base fluid [g]

θ- Temperature difference [^0C]

Q_s- Discharge through shell [mm^3/sec]

Q_t- Discharge through spiral tube [mm^3/sec]

D_e- Effective diameter of shell [mm]

Subscripts

h – hot fluid

c- cold fluid

bf – base fluid

max- maximum

o- outer

i-inner

avg –average

s- shell

Greek Symbols

K - Thermal conductivity [W/m K]

ρ – Density [kg/m^3]

μ – Dynamic viscosity [Pa s]

υ – Kinematic viscosity [m^2/s]

δ- Curvature ratio

ψ- angle of arc [rad]

$\Delta\theta_{LMTD}$ - Log mean temperature difference [^0C]

ε- Effectiveness of heat exchanger

1 INTRODUCTION

Spiral tube heat exchangers are 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 through which fluid is entering into the spiral coils. This spiral coil is installed in a shell, where another fluid is circulated around tube, leads to transfer of heat between the two fluids.

Curved tubes has the ability to transfer large amounts of heat with less space and size hence, they have attracted considerable research attention. Many researchers have studied experimentally and numerically the performance of simple helical coils for heat transfer enhancement. Very few researchers have studied the effect of pitch and curvature ratio on the heat exchanger performance. Paper reviewed for this dissertation work are categorize under the helical and spiral tubes, then design of compact heat exchanges and application of Nano fluid for heat transfer augmentation.

Nunez et al. [1] investigated the application of a graphical tool for the preliminary design of heat exchangers. The approach, originally developed for the case of shell and tube heat exchangers, later it is extended to the cases of spiral and welded compact exchangers. Their tool depicts the design space where a number of combinations of geometrical parameters meet the heat duty and allowable pressure drops. The enclosed area between three curves is a design space, a curve that represents the particular heat responsibility and the curves that represent the pressure drop on the hot and cold sides. This demonstration gives the designer the largely view that allows him to bring together design condition with the choice of the unit for a given appliance.

Patil et al. [2] they proposed the simple method for designing of helical coil heat exchanger (HCHE). This HCHE offers lot of advantages over double pipe heat exchanger. One of the important factors of using a helical coil heat exchanger is the space requirement in helical coil heat exchanger is less as compared to straight tube heat exchanger.

Tandal et al. [4] they designed and fabricate the innovative Pancake type heat exchanger for process industry. Cold fluid flows in spiral path while hot fluid flows in axial path. Experimental results and theoretical values are compared by the parameter called overall heat transfer coefficient. An analytical model was developed for carrying out design simulations of the Pancake type heat exchanger. Total of eight pancakes are used in their heat exchanger. The results show 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%.

Bhavsar et al. [5] they streamline the design procedure for the spiral tube heat exchanger, as the standard design procedure is not available and the information for designing the spiral tube heat exchanger is in the scatter form. Afterwards they have fabricated the spiral tube heat exchanger and carry our experimentation and measure the performance of the spiral tube heat exchanger. Their results show that spiral tube heat exchanger is compact in size and more heat transfer is occurred as compared to shell and tube heat exchanger.

From the literature reviewed for this work it is found that very little information is available on design of spiral tube heat exchangers that too is limited for both fluids flowing in spiral paths. The design procedure for spiral tube heat exchanger is in scattered form and no specific procedure is available for designing the spiral tube heat exchangers. Therefore, the present research work is carried out for establishing the design procedure of the different compact spiral tube heat exchangers.

1.1 Assumption in Design of Spiral Tube Heat Exchanger

1. Properties of cold water and hot water are considered as constant, at an average value of inlet and outlet temperature with little loss in accuracy.
2. Flow through heat exchanger is fully developed, steady and constant.
3. Fluid stream experiences little or no change in their velocities and elevations hence the Kinetic Energy and Potential energy changes are negligible.
4. Outer surface of heat exchanger is assumed to be perfectly insulated.
5. There is no fouling in heat exchanger.

2 DESIGNING OF SPIRAL TUBE HEAT EXCHANGER

2.1 Design of Shell

There is no standard method available for calculating the various design parameters of the spiral tube heat exchanger, such as shell inside diameter, length of shell, curvature ratio, developed length of spiral tube and total length of spiral tubes. Therefore, the methodology followed by different researcher studied in literature review is used for the determination of these parameters. Following data shown in Table 1 is considered for calculating the shell parameters.

Table: 1 Design Parameter for Spiral coil

Parameters	Dimensions
O.D. of copper tube, mm (d_o)	12
I.D. of copper tube, mm (d_i)	10
Number of Spiral coils (n)	3
Number of Turns	4
Spiral Pitch, mm (P)	20
I.D. of Spiral, mm (D_i)	114.02
O.D. of Straight tube, mm (d_{ho})	27
I.D. of Straight tube, mm (d_{hi})	25

2.2 Inside Diameter of Shell (D_{is})

Inside diameter of shell is calculated as,

$$D_{is} = 2\,(R_0 + R_{h0}) \qquad \text{(Eqn. 1)}$$

$$R_0 = R_i + 3P \qquad \text{(Eqn. 2)}$$

2.3 Length of Shell (L_s)

Length of shell required for the heat exchanger is calculated as,

$$L_s = \frac{R_0^2 - R_i^2}{a} \qquad \text{(Eqn. 3)}$$

$$a = P\,\frac{\pi}{2} \qquad \text{(Eqn. 4)}$$

2.4 Curvature ratio (δ)

Curvature ratio is the ratio of tube diameter to the diameter of spiral is calculated as,

$$\delta = \frac{d_i}{D_i} \qquad \text{(Eqn. 5)}$$

2.5 Developed Length of Spiral Coil (L_0)

Length of the spiral coil used in spiral tube heat exchanger is calculated as,

$$L_0 = B_1 + B_2 + B_3 + B_4 + B_5 + B_6 + B_7 \qquad \text{(Eqn. 6)}$$

or

$$L_0 = L_1 + L_2 + L_3 + L_4 + L_5 + L_6 + L_7$$

$$B = r_n\,\psi \qquad \text{(Eqn. 7)}$$

$$r_n = (R_i + k\,t) \qquad \text{(Eqn. 8)}$$

$$k = \frac{1}{3} \quad \text{if } R_i \ll 2\,t \qquad \text{(Eqn. 9)}$$

In case of Copper $$k = \frac{1}{2} \quad \text{if } R_i > 2\,t \qquad \text{(Eqn. 10)}$$

2.6 Total length of Copper Tubes in Heat Exchanger (L_T)

The total length of copper tubes required in the heat exchanger is calculated as,

$$L_T = n\,L_0 \qquad \text{(Eqn. 11)}$$

Table: 2 Design Parameter for Spiral Tube Heat Exchanger

Parameter	Tube Side	Shell Side
Inner temperature °C	35	70
Outlet temperature °C	43.3	65
Mass flow rate Kg/s	0.05	0.0833
Density kg/m^3	989.1	979.4
Specific heat KJ/kg K	4.18	4.18
Dynamic viscosity Ns/m^2	5.77 ×10^{-4}	4.2 × 10^{-4}

All the properties of density, specific heat, viscosity, and thermal conductivity of hot water considered for the shell side calculations are obtained at the average of hot inlet and outlet temperature as $T_{h,avg}$.

$$T_{h,avg} = \frac{T_{h1} + T_{h2}}{2} \qquad \text{(Eqn. 12)}$$

Similarly, all the properties of density, specific heat, viscosity, and thermal conductivity of cold water considered for the tube side calculations are obtained at the average of cold inlet and outlet temperature as $T_{c,avg}$.

$$T_{c,avg} = \frac{T_{c1} + T_{c2}}{2} \qquad \text{(Eqn. 13)}$$

2.7 Energy Balance

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

$$Q_h = Q_c \qquad \text{(Eqn. 14)}$$

$$m_h\,C_{ph}\,(T_{h1} - T_{h2}) = m_c\,C_{pc}\,(T_{c2} - T_{c1}) \qquad \text{(Eqn. 15)}$$

For all the further calculation average of hot and cold heat transfer rate is taken,

$$Q_{avg} = \frac{Q_c + Q_h}{2} \qquad \text{(Eqn. 16)}$$

Heat transfer rate is also calculated from Newton's law of cooling as,

$$Q = U\,A_s\,\left(\Delta\theta_{(LMTD)}\right) \qquad \text{(Eqn. 17)}$$

A_s is the outer surface area of heat exchanger in m^2

$$A_s = n\,\pi\,d_0 L_o \qquad \text{(Eqn. 18)}$$

Flow arrangement selected is counter flow and accordingly LMTD is calculated as,

$$\Delta\theta_{(LMTD)} = \frac{(\theta_2 - \theta_1)}{\ln\frac{(\theta_2)}{(\theta_1)}} \qquad \text{(Eqn. 19)}$$

$$\theta_2 = (T_{h2} - T_{c1}) \qquad \text{(Eqn. 20)}$$

$$\theta_1 = (T_{h1} - T_{c2}) \quad \text{(Eqn. 21)}$$

2.8 Effectiveness of Heat Exchanger

Effectiveness of heat exchanger is calculated as,

$$\epsilon = \frac{Q_{avg}}{Q_{max}} \quad \text{(Eqn. 22)}$$

$$Q_{max} = (mC_P)_{min}(T_{h1} - T_{c1}) \quad \text{(Eqn. 23)}$$

2.9 Number of Transfer Units of Heat Exchanger

Number of Transfer Units for counter flow is the measure of effectiveness of heat exchanger, which is calculated as,

$$NTU = \frac{1}{R-1} \ln\left(\frac{R-1}{R\epsilon - 1}\right) \quad \text{(Eqn. 24)}$$

$$R = \frac{C_{min}}{C_{max}} \quad \text{(Eqn. 25)}$$

$$NTU = \frac{U A_s}{C_{min}} \quad \text{(Eqn. 26)}$$

2.10 Reynolds Number (Re) of Tube Fluid

Reynolds number for cold side i.e. the fluid flowing in the spiral tube is calculated as follows,

$$Re_c = \frac{\rho_c V_c d_i}{\mu_c} \quad \text{(Eqn. 27)}$$

Velocity (V) of fluid flowing through the spiral coil is calculated as,

$$Q_t = A_i V_c = \frac{\pi}{4} {d_i}^2 V_c \quad \text{(Eqn. 28)}$$

2.11 Nusselt Number (Nu) of Tube Fluid

Using Kalb and Seader Correlation for determining the Nusselt number for the flow in the spiral tubes,

$$Nu_c = 0.836 \; De^{0.5} \; {Pr_c}^{0.1} \quad \text{(Eqn. 29)}$$

$$De = Re_c \sqrt{\frac{r_i}{R_i}} \quad \text{(Eqn. 30)}$$

$$Pr_c = \frac{\mu_c C_{Pc}}{K_c} \quad \text{(Eqn. 31)}$$

2.12 Heat Transfer Coefficient of Inner Tube Fluid

Heat transfer coefficient on cold side i.e. inside of spiral tube is calculated as,

$$h_c = \frac{Nu_c K_c}{d_i} \quad \text{(Eqn. 32)}$$

2.13 Reynolds Number (Re) of Shell Fluid

Reynolds number for shell side i.e. the fluid flowing in the shell is calculated as follows,

$$Re_h = \frac{\rho_h V_h D_e}{\mu_h} \quad \text{(Eqn.33)}$$

Effective diameter or hydraulic diameter of shell in calculated as;

$$D_e = D_{is} - 2\,(d_{ho}) - 8\,(d_o) \quad \text{(Eqn.34)}$$

Velocity of fluid flowing through the shell is calculated as,

$$Q_s = A_e V_h = \frac{\pi}{4} {D_e}^2 V_h \quad \text{(Eqn. 35)}$$

2.14 Nusselt Number (Nu) of Shell Fluid

Nusselt number for flow in shell side is calculated by the Correlation used in literature,

$$Nu_h = 0.04\ Re_h^{0.8}\ Pr_h^{0.4} \quad \text{(Eqn.36)}$$

$$Pr_h = \frac{\mu_h\ C_{Ph}}{K_h} \quad \text{(Eqn. 37)}$$

2.15 Heat Transfer Coefficient of Shell Fluid

Heat transfer on shell side i.e. at the outside of spiral coil is calculated as,

$$h_h = \frac{Nu_h\ K_h}{d_o} \quad \text{(Eqn. 38)}$$

2.16 Overall Heat Transfer Coefficient

It depends upon on the inside heat transfer coefficient of tube and outside heat transfer coefficient of heat exchanger is calculated as,

$$\frac{1}{U_o} = \frac{1}{A_{si}\ h_c} + R + \frac{1}{h_h\ A_{so}} \quad \text{(Eqn. 39)}$$

$$\frac{1}{R} = \frac{1}{R_{s1}} + \frac{1}{R_{s2}} + \frac{1}{R_{s3}} + \frac{1}{R_{st1}} + \frac{1}{R_{st2}} \quad \text{(Eqn. 40)}$$

Total outer heat transfer surface area is calculated as,

$$A_{so} = (n\ \pi\ d_o\ L_o) + (n_1\ \pi\ d_{ho}\ L_{st}) \quad \text{(Eqn. 41)}$$

Total inside heat transfer surface area is calculated as,

$$A_{si} = (n\ \pi\ d_i\ L_o) + (n_1\ \pi\ d_{hi} L_{st}) \quad \text{(Eqn. 42)}$$

L_s is the length of straight tube, n_1 is straight header tube = 2

$$R_{s1} = R_{s2} = R_{s3} = \frac{(d_o - d_i)}{2\ \pi\ K\ L_o\ \ln\left(\frac{d_o}{d_i}\right)} \quad \text{(Eqn. 43)}$$

$$R_{st1} = R_{st2} = \frac{(d_{ho} - d_{hi})}{2\ \pi\ K\ L_{st}\ \ln\left(\frac{d_{ho}}{d_{hi}}\right)} \quad \text{(Eqn. 44)}$$

Hence by adopting above design procedure two spiral tube heat exchanger with specifications shown in the table 3 were designed and compared.

Table: 3 Dimensions of Spiral Tube Heat Exchangers

Parameters	Spiral Tube Types	
	Type – A	Type - B
O.D. of copper tube (mm)	12	12
I.D. of copper tube (mm)	10	10
Number of Spiral coils	3	3
Number of Turns	4	4
Spiral Pitch (mm)	25	20
Curvature Ratio	0.1136	0.0877
I.D. of Spiral (mm)	88.5	114.02
O.D. of Spiral (mm)	238.5	234.02

I.D. of Shell (mm)	278	278
O.D. of Shell (mm)	280	280
Length of Shell (mm)	270	270
Thickness of Shell (mm)	1	1
O.D. of Straight tube (mm)	27	27
I.D. of Straight tube (mm)	25	25
Total length of Copper Tube (mm)	5880	5880
Material of Shell	S.S.	S.S.

Fig. 1 and 2 shows the schematic drawing of spiral coils in the Auto Cad software, after calculating the above-mentioned parameters.

Fig1: Spiral Tube Type A

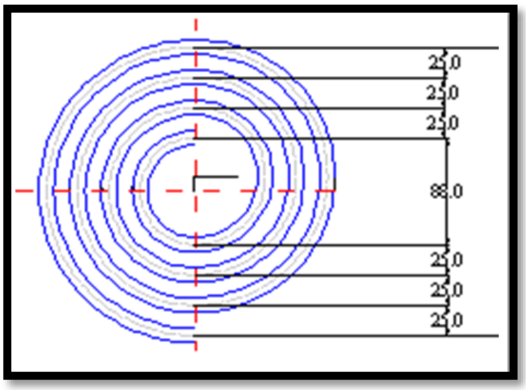

Fig2: Spiral Tube Type B

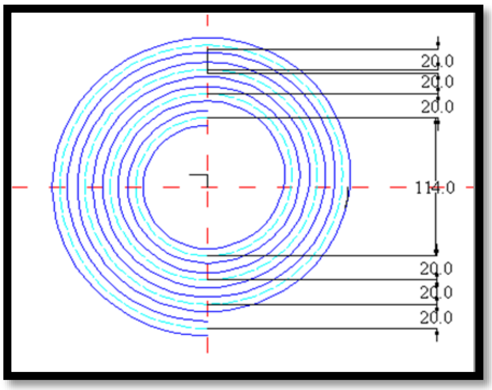

Fig. 3 and 4 shows the photographic image of spiral coils fabricated with the same dimensions obtained by design calculation.

Fig.3 Photographic Image of Spiral Coils Type A

Spiral coils are ready for further joining with the straight header tube.

Fig.4 Photographic Image of Spiral Coils Type B

Following data shown in Table 2 is adopted for further calculation of STHE,

Based on above theory and design calculations of STHE, experimental set up is developed and fabricated. The experimental results clearly states that the high curvature ration and high spiral pitch heat exchanger generates more secondary turbulent flow which is responsible for high heat transfer in the same space. Hence while designing of spiral tube heat exchanger the important parameters are curvature ratio and spiral pitch.

3 CONCLUSION

This paper is an attempt to unite the design procedure for spiral tube heat exchanger by incorporating the mathematical formulas. This leads to the formulation of systematic procedure for designing of heat exchanger. This design method of heat exchanger can be used for designing the similar kind of compact heat exchanger. The main parameters that are to be taken care while designing of heat exchangers is curvature ratio and spiral pitch.

REFERENCES

1. M. P. Nunez, G. T. Polley, G. M. Rodríguez (2013), Applied Thermal Engineering, 1- 8.

2. R. K. Patil, B. W. Shende, P. K. Ghosh (1981), Chemical Engineering Journal.

3. P. Naphon, S. Wongwises (2005), Expt. Thermal and Fluid Science 29, 511–521.

4 M. S. Tandal, S. M. Joshi (2008), 5th WSEAS Int. Conf. on HMT'08, Acapulco, Mexico, January 25-27.

5. J. J. Bhavsar, V. K. Matawala, S. Dixit (2013), International Journal of Mechanical and Production Engineering, 2320-2092, Volume – 1, Issue – 1.

6. H. N. Mohammed (2009), Diyala Journal of Engg Sciences Vol. 02 pp. 1-14.

7. M. G. Bandpy, H. Sajjadi (2010), International Journal of Mechanical and Materials Engineering 1:2.

8. Yanuar, N. Putra, Gunawan M. Baqi (2011), IJRRAS 7 (3).

9. P. Naphon, S. Wongwises (2002), Inter. Comm. Heat Mass Transfer, vol. 29, No. 6, pp. 797-809.

10. P. Naphon, J. Suwagrai (2007), International Journal of Heat Mass Transfer, Elsevier Press, 50 444 – 451.

11. H. Shokouhmand, M. R. Salimpour, M. A. A. Behabadi (2008), International Communications in Heat and Mass Transfer 35 84–92.
12. G. E. Kondhalkar, V. N. Kapatkat (2012), International Journal of Modern Engineering Research, Vol.2, Issue.3, pp-930-936.
13. N. E. Wijeysundera, J. C. Ho, S. Rajasekar (1996), International Journal of Heat and Mass Transfer, Vol. 23 No. 5, pp 623-631.
14. S. S. Pawar, V. K. pawar (2013), Experimental Thermal and Fluid Science, 44, 792–804.
15. G. N. Deshpande, N. V. Sali (2014), Applied Mechanics and Materials, Trans Tech Publications, Switzerland Vols. 592-594, pp 1564-1569.