

Thermal Design of Shell and Tube Heat Exchanger Using Elliptical Tube

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Abstract- Energy saving is most important parameter in Industrial & Chemical Sector. For industrial growth it is necessary to enhance heat transfer in shell and tube Heat Exchanger. In the present study, the conventional cross section of tube is modified from circular to elliptical. The code developed for circular tube is giving the same result as available in existing literature. Then the code is modified for elliptical tube and heat transfer coefficient is determined for the various ratio of major axis to minor axis. It is found that heat transfer coefficients is better when this ratio is less than one as compared to the ratio more than one. It is also reported that when this ratio is less than 0.5, then pressure drop in shell become almost double. Finally it is concluded that the best results are obtained when this ratio near to 0.75.

Keywords: Heat Exchanger, Shell and tube, Elliptical tube

1. Introduction

Shell and tube Heat Exchangers (STHEX) are the equipment which gives the flow of thermal energy between two or more fluids at different temperatures [1]. STHEX are used in huge industrial applications e.g. power plants, process industries, petro chemical industries, waste heat recovery etc. The heat Transfer enhancement technique by using extended surface, change of shape, using Nano particle fall under the category of passive methods. James E. O' Brien et al. (2000)[2], use narrow rectangular duct fitted with elliptical tube in cross flow. They showed the increased heat transfer along the sides and downstream of the elliptical tube. Xian-hui Tan et al. (2013) [3] uses twisted oval tube heat exchanger for improving the heat transfer coefficient of the tube side. A.R Sajadi et al. (2014) [4], They find that in alternating elliptical axis tube decreasing the aspect ratio and pitch length increases heat transfer and flow resistance. They also found that alternating elliptical axis tube perform better than circular tube. Above studies showed that work in pure non-circular tubing in STHEX is less. Also the heat transfer coefficient in tube side and shell side is not determined for elliptical tube.

The present work investigate the Heat transfer in STHEX using elliptical tubes. It focus on finding the Heat transfer coefficients in shell side and tube side and finding the overall heat transfer coefficient. STHEX are using elliptical tubes mounted in a cylindrical shell such that tubes are parallel to the shell along longitudinal axis.

2. Design Procedure

In designing the basic dimensions such as shell diameter (D_s), tube outer diameter (d_o), Baffle spacing (B) are taken from literature. Other parameter such as mass flow rate of hot fluid and

cold fluid. Inlet and outlet temperature of hot fluid and cold fluid etc. are taken from table 2.

Initially the value of overall Heat transfer co-efficiently is not known to us [5]. So assuming $U=500$. On the basis of above values the tube length, Number of tubes, shell side and tube side heat transfer coefficients, overall Heat transfer coefficients etc are found[6]. Then the above procedure is coded in FORTRAN 95.

3. Mathematical Models

In STHEX we first find Heat load of the STHEX using the mass flow rate and inlet and outlet temperature of fluids [5],

$$Q = m_c C_{pc} \Delta = m_h C_{ph} \Delta t \quad (1)$$

The Flow correction factor is found by using the following relation [7],

$$F = \frac{\left(\sqrt{R - \frac{1}{R}} - 1 \right) \left(\ln \left(1 - \frac{P}{1 - PR} \right) \right)}{\frac{\ln \left(2 - P(R + 1 - \sqrt{R + 1}) \right)}{\left(2 - P(R + 1 + \sqrt{R + 1}) \right)}} \text{ for } (R \neq 1)$$

$$\frac{\sqrt{2P}}{[(1 - P) \ln \{ (2 - P(2 - \sqrt{2})) / (2 - P(2 + \sqrt{2})) \}]} \quad (2)$$

For ($R = 1$)

$$R = \frac{T_{h,i} - T_{h,o}}{T_{c,o} - T_{c,i}}, \quad P = \frac{T_{c,o} - T_{c,i}}{T_{h,i} - T_{c,i}}$$

The log-mean temperature difference for a STHEX can be calculated from the following relation

$$\Delta T_{lm} = \frac{(T_{h,i} - T_{c,o}) - (T_{h,o} - T_{c,i})}{l_n \left(\frac{T_{h,i} - T_{c,o}}{T_{h,o} - T_{c,i}} \right)} \quad (3)$$

The Heat transfer area can be found by using the following relation [8]

$$A = \frac{Q}{FU\Delta T} \quad (4)$$

The no. of tubes depends on shell size, tube layout, outer diameter, pitch size, no. of passes.

The Number of tubes can be found by following relation [1]

$$N_t = C \left(\frac{D_s}{d_o} \right)^{n_1} \quad (5)$$

The value of C and n, can be taken from table 1.

Table 1 Empirical Constant for triangular pitch and square pitch

No of Passes	Triangular pitch S _t =1.25 d _o C	pitch n ₂	Square tube S _t =1.25 C	n ₁
1	0.319	2.142	0.215	2.207
2	0.249	2.207	0.156	2.291
4	0.125	2.285	0.158	2.263
6	0.0743	2.499	0.0402	2.617

The tube length can be calculated as follows

$$L = \frac{A}{\pi d N_t} \quad (6)$$

Where, d_o is outer diameter, N_t is number of tubes.

$$d_i = 0.8 d_o$$

$$Pr = \mu C_p / K$$

To find the Reynolds number, the flow velocities, clearance, surface area of tube, equivalent diameter of tube etc. are calculated as follows [9],

$$V_t = \frac{m_t}{\frac{\pi}{4} d^2 P_t} \cdot \frac{n}{N_t}$$

$$CI = P_t - d_o$$

$$a_s = \frac{D_s BCI}{P_t}$$

$$V_s = \frac{m_s}{a_s P_s}$$

$$R_{et} = \frac{P_t V_t}{\mu_t} d_i$$

$$d_e = \frac{4 \times (\pi \cdot a \cdot b)}{\pi \sqrt{2(a^2 + b^2)} - \frac{(a-b)^2}{2}} \quad (7)$$

Above calculated Reynolds number are used to find Heat transfer coefficient in shell side and in tube side [9],

$$h_t = \frac{K_t}{d_o} 0.027 R_{et}^{0.8} P_{rt}^{1/3} \left(\frac{\mu_t}{\mu_w} \right)^{0.14} \quad (8)$$

(R_{et} > 10,000)

$$h_s = \frac{k_s}{d_e} 0.36 R_{es}^{0.55} P_{rs}^{1/3} \left(\frac{\mu_t}{\mu_w} \right)^{0.14} \quad (9)$$

The overall Heat transfer coefficient can be find by the above calculated values of Heat transfer coefficient [10],

$$U = \frac{1}{\left(\frac{1}{h_s} \right) + R_{fs} + \frac{d_o}{d_s} \left(R_{fi} + \frac{1}{h_t} \right)}$$

The program is run by iterating with possible combinations of standard dimensions and the overall Heat transfer coefficients is obtained. This obtained value of the U are compared and set as maximum possible overall Heat transfer coefficient and calculate the difference between old and new value till this value coverage approximately to 0.001.

These above equations are coded in Fortran 95 till the design parameters corresponding to the maximum overall Heat transfer coefficient is obtained.

4. Objective Functions

There are many alternative designs which may give almost same value therefore it is necessary to optimize the design. To find Heat transfer and pressure drop for fluid flowing is simple, but because of complex flow conditions the Heat transfer and pressure loss with in STHEX is not straight-forward[6].

The major components of a shell and tube heat exchanger are tubes (tube bundles) shell, nozzles, baffles and flow pattern. Among these tubes are the basic components which provides the required surface area for heat transfer.

In present work design of tubes is modified taking elliptical cross section of tubes instead of circular. In which major diameter equal to 2b, minor diameter equal to 2a, x axis of square equal to a₁, y axis of square equal to b₁

A theoretical model for predicting the performance of a shell and tube heat exchanger using elliptical tubing and validating the predictions are done.

The shell is cylindrical shape with a circular cross section. The E shell is most common due to its low cost and simplicity.

Design of tube has been carried out in STHEX to predict the surface area, number of tubes, length of tube, overall heat transfer coefficient and pressure drop across the STHEX. Assume the shell diameter, baffle spacing, number of pass and take thermophysical properties of working substance from table 2 on both shell and tube side.

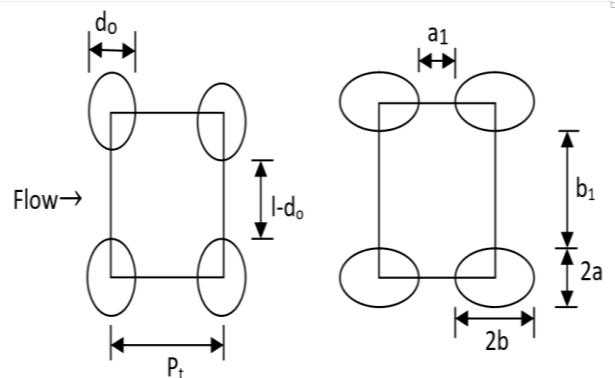


Fig. 1: Circular and Elliptical tubes in Square Pitch

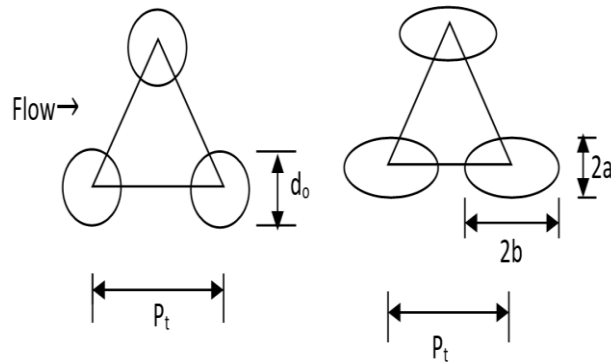


Fig. 2: Circular and Elliptical tubes in Triangular Pitch

Table 2: The process input and physical properties for different case studies

	Mass flow Rate (kg/s)	T _{input} (°C)	T _{output} (°C)	P (kg/m ²)	C _p (kj/kgk)	M (Pa s)	K(w/mk)	R (m ² k/w)
Case 1 : Shell side : methanol	27.80	95.00	40.00	750.00	2.84	0.00034	0.19	0.00033
Tube side : sea water	68.90	25.00	40.00	995.00	4.20	0.0008	0.59	0.0002
Case 2 : Shell side : kerosene	5.52	199.00	93.30	850.00	2.47	0.0004	0.13	0.00061
Tube side : crude oil	18.50	37.80	76.70	995.00	2.05	0.00358	0.13	0.00061
Case 3 : Shell side : distilled water	22.07	33.90	29.40	995.00	4.18	0.0008	0.62	0.00017
Tube side : raw water	35.31	23.90	26.70	999.00	4.18	0.00092	0.62	0.00017

5. Result and Discussion

A theoretical study of heat transfer coefficient in shell side and tube side is done. The shell is cylindrical in shape with a circular cross section is taken for study. The Design of tube has been carried out in STHEX to predict the surface area, number of tubes and their lengths. The overall heat transfer coefficient and pressure drop across the shell and tube side is determine for known heat duty. The thermophysical properties of working substance on both shell and tube side is taken from table 2. The square pitch is chosen for reason of convenience in cleaning the outside of the tubes.

Table 3: Input parameter

Parameter(m)	
Outer diameter of tube(d_o)	0.02
Shell diameter (D_s)	0.894
Baffle spacing(B)	0.356

Assumed the overall heat transfer coefficient and fix input parameter like tube outside diameter, shell diameter, baffle spacing. First develop the code for circular cross section of tube and compare results with the existing literature. When the results of code developed and literature are similar then alter the design

of tubes. As tubes are main component in STHEX. So main area of focus is designing of tube.

Table 4: Comparison of present work with literature is shown in table

Parameters	Literature (Caputo 2008)	Present Work (Circle)
L(m)	4.83	4.03
N _t	918	988
V _t (m/s)	0.75	0.69
h _t (W/m ² k)	3812	3611
f _t	0.028	0.0288
P _{dt} (Pa)	6251	4678
V _s (m/s)	0.58	0.582
h _s (W/m ² k)	1573	1813
P _{ds} (Pa)	35789	29779
U(W/m ² k)	615	676
A _s (m ²)	278.6	256

The following table shows the results of elliptical tube. When the circular tube are replaced by elliptical tube the overall heat transfer coefficient increases and surface area decreases. Also when the ratio of major axis to minor axis ($z=b/a$) is less than one the tube side and shell side velocity increases by

9.8% and 15.3%. The heat transfer coefficient in tube side and shell side increases by 14.5% and 20.2%.

Table 5: Different values of ratio of major axis to minor axis

$z=b/a$	0.75	1.0	1.25
L(m)	2.05	2.75	3.438
N_t	1666	998	681
V_t	0.7579	0.69	0.659
h_t	4135	3611	3336
f_t	0.0305	0.0288	0.0275
P_{dt}	4457	3536	3151
V_s	29.9	25.91	23.17
h_s	17589	14623	12713
P_{ds}	1.46×10^9	9.99×10^8	7.43×10^8
U_o	1022	1005	990
A_s	169	172	175

6. Conclusion

In this work the theoretical testing of shell-side and tube side heat transfer coefficient is performed. The circular tubes are replaced by elliptical tubes. The codes is developed and first validated by taking the circular tube and compare the results with the literature then replace the circular tube by elliptical tube.

The main conclusion are summarized or follows.

1. When the ratio of major axis to minor axis ($z=b/a$) is less than one the increase in tube side flow velocity while when this ratio greater than one we get reduced velocity in tube side.
2. Also, when this ratio is less than one, the heat transfer coefficient in shell side increases by 20.2% and in tube side increases by 14.5%.
3. Both the shell side and tube side heat transfer coefficient increases. Therefore the combined effect of both also increases the overall Heat transfer coefficient.
4. The overall Heat transfer coefficient increases and reduction in surface area of the tube, also the setup cost of equipment reduces.
5. The only drawback is slightly increment in pressure drop in shell side. That is to be optimize by taking various ratio of axis (z). Finally it is concluded that when $z=0.75$ the best results are obtained.

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