INTERNATIONAL JOURNAL OF RESEARCH IN AERONAUTICAL AND MECHANICAL ENGINEERING

ISSN (ONLINE): 2321-3051

Vol.4 Issue 2,

February 2016

Pgs: 58-66

AN OVERVIEW OF SHELL AND TUBE HEAT EXCHANGER PERFORMANCE

Asawari Barde

Department of Mechanical Engineering, Bharati Vidyapeeth College of Engineering, University of Mumbai

Abstract

A heat exchanger is equipment which transfers the energy from a hot fluid to a cold fluid, with maximum rate and minimum investment and running costs. There are various types of heat exchangers which are available in industry. But shell and tube type heat exchanger is the most widely used heat exchanger. This paper represents the study of shell and tube type of heat exchanger along with the literature reviews of several scholars who have given the contribution in this regards. Classification, basic construction design and its application are also described in details inside the paper.

Keywords - Shell and tube heat exchanger, classification, basic constructional detail, design methods, applications and literature review.

1. INTRODUCTION

Transfer of heat from one fluid to another is an important operation for most of chemical industry. So it is necessary to develop the equipments which transfer the heat with maximum rate and minimum costs. Such equipments for efficient transfer of heat are called as heat exchangers. Thus heat exchangers facilitate the exchange of heat between the fluids that are different temperature while keeping them from mixing with each other. Heat exchangers have undergone numerous modifications over the ages and have become quite efficient compared to their predecessors. There are different types of heat exchangers with different designs, materials and have been customized to meet specific needs. Out of this Shell and Tube heat exchanger without doubt, one of the most widely used heat exchanger in oil refineries and other large chemical process, and it suitable for higher pressure application.

2. CLASSIFICATION

The popularity of shell and tube heat exchanger has resulted in a standard being developed for their use by the Tubular Exchanger Manufactures Association (TEMA).According to this the first letter indicates the front header type, the second letter the shell type and the third letter the rear header type. The header type is selected based on the applications. The TEMA header types are shown below.

The three most common types of shell-and-tube exchangers are

A. Fixed tube-sheet design (L, M, and N type rear header)

This is a very popular version as the heads can be removed to clean the inside tubes. The front head piping must be unbolted to allow the removal of front head, if this is undesired this can be avoided by applying a type A front head. It is not possible to clean the outside surface of the tubes as these are inside the fixed part. Chemical cleaning can be used.

B. U-tube design (front header and M type rear header)

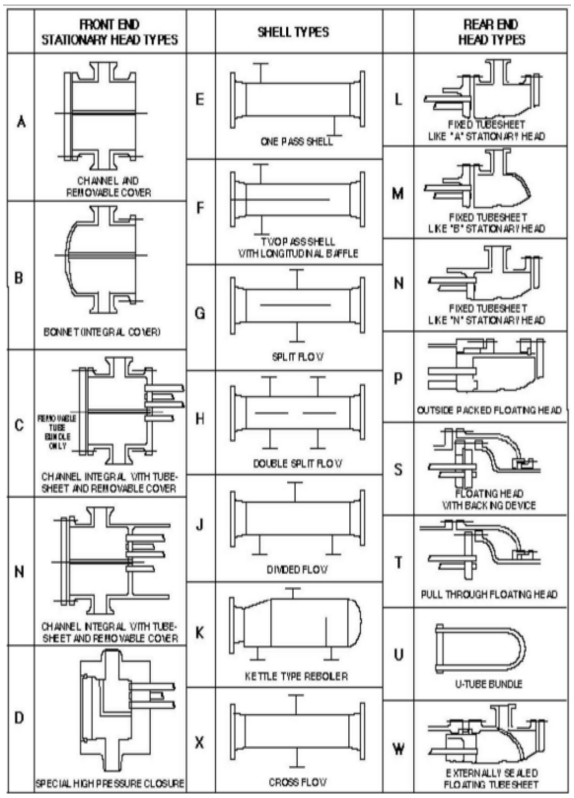
It permits unlimited thermal expansion the tube bundle can be removed for cleaning and small bundle to shell clearance can be achieved

C. Floating-head type (P, S, T, W type rear headers)

A floating head is excellent for applications where the difference in temperature between the hot and cold fluid causes unacceptable stresses in the axial direction of the shell and tubes. The floating head can move.

Thus In all three types, the front-end head is stationary while the rear-end head can be either stationary or floating depending on the thermal stresses in the shell, tube, or tube-sheet, due to temperature differences as a result of heat transfer.

Fig.1: TEMA nomenclature (Tubular Exchanger Manufacturers Association)



3. BASIC COMPONENTS

Basic components of the tube and shell type heat exchanger are as follows;

A. Tubes

The tubes are the basic components of a shell and tube type heat exchanger. Tubes may be seamless or welded having diameters 5/8 inch, 3/4inch, and 1inch. Tubes materials shouldbe highly thermal conductive for proper heat transfer .Most commonly it is made up of copper and steel alloys. Other alloys of nickel, titanium, or aluminum may also be required for specific applications.

B. Tube sheet

The tubes are fixed with tube sheet that form the barrier between the tube and shell fluids. The tubes can be fixed with the tube sheet using ferrule and a soft metal packing ring. The tubes are attached to tube sheet with two or more grooves in the tube sheet wall by „tube rolling‟. The tube metal is forced to move into the grooves forming an excellent tight seal. This is the most common type of fixing arrangement in large industrial exchangers. The tube sheet thickness should be always greater than the tube outside diameter to make a good seal.

C. Shell

Shell is the container for the shell fluid and the tube bundle is placed inside the shell. Shell diameter should be selected in such a way to give a close fit of the tube bundle. The clearance between the tube bundle and inner shell wall depends on the type of exchanger. Shells are usually fabricated from standard steel pipe with satisfactory corrosion allowance.

D. Baffles

Baffles are used to increase the fluid velocity by diverting the flow across the tube bundle to obtain higher transfer co-efficient. The distance between adjacent baffles is called baffle-spacing. Baffles are held in positioned by means of baffle spacers. Closer baffle spacing gives greater transfer co-efficient by inducing higher turbulence. The pressure drop is more with closer baffle spacing.

E. Tube side channels and nozzles

This are made up of alloy material and it is used to control the flow of the tube side into and out of the tubes of the exchanger.

F. Channel covers

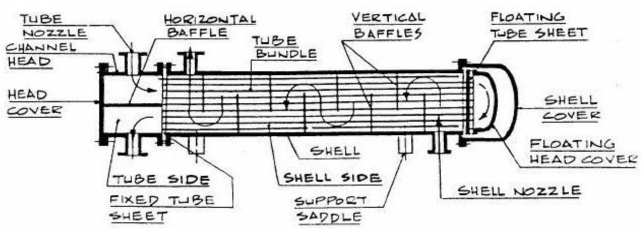


Fig.2: Heat exchanger parts

The channel covers are round plates that bolt to the channel flanges and can be removed for the tube inspection without disturbing the tube side piping. In smaller heat exchangers, bonnets with flanged nozzles or threaded connections for the tube side piping are often used instead of channel and channel covers.

4. DESIGN

Shell and tube heat exchanger is designed by trial and error calculations. The main steps of design following the Kernmethodare summarized as follows:

Step 1

Obtain the required thermo physical properties of hot and cold fluids at the Caloric temperature or arithmetic mean temperature and Perform energy balance and find out the heat duty (*Q*) of the exchanger.

$$Q_g = Q_k = m_k C_k \left(t_1 - t_2\right) = m_g C_g \left(T_2 - T_1\right)$$

Step 2

Assume a reasonable value of overall heat transfer coefficient $U_{O,assm}$. Determine the LMTD and correction factor calculate the LMTD

$$LMTD = \frac{\left(T_1 - t_2\right) - \left(T_2 - t_1\right)}{\ln\left[\frac{\left(T_1 - t_2\right)}{\left(T_2 - t_1\right)}\right]}$$

Step 3

Decide type of shell and tube exchanger (fixed tube sheet, U-tube etc.). Select the tube pitch (P_T), determine inside shell diameter (D_s)

Step 4

Calculate heat transfer area (*A*) required

$$A = \frac{Q}{U_{O,assm} \times LMTD \times F_t}$$

Step 5

Select tube material, decide the tube diameter (ID=d_i OD =d_o), its wall thickness in terms of BWG or SWG) and tube length (L). Calculate the number of tubes (n_t)

$$n_t = \frac{A}{\pi \times d_O \times L}$$

Calculate tube side fluid velocity

$$u = \frac{4 \cdot m\left(\frac{n_p}{n_t}\right)}{\pi \times \rho \times d_i^2}$$

If u <1 m/s, fix $n_p$so that,

$$\mathrm{Re} = \frac{4 \cdot m\left(\frac{n_p}{n_t}\right)}{\pi \times \mu \times d_i}$$

Step 6

Determine the tube side film heat transfer coefficient (h_i) using the suitable form of Sieder-Tate equation in laminar and turbulent flow regimes. Estimate the shell-side film heat transfer coefficient (h_o)

$$j_H = \frac{h_O D_e}{k}\left(\frac{C\mu}{k}\right)^{-\frac{1}{3}}\left(\frac{\mu}{\mu_k}\right)^{-0.14}$$

The clean overall heat transfer coefficient is given by;

$$U_{O,cal} = \frac{1}{\left[\frac{1}{h_O} + R_{d,O} + \frac{A_O}{A_i}\left(\frac{d_O - d_i}{2k_w}\right) + \frac{A_O}{A_i}\frac{1}{h_i} + \frac{A_O}{A_i}R_{d,i}\right]}$$

$$\frac{U_{O,cal} - U_{O,assm}}{U_{O,assm}} < 30\%$$

Step 7

If the calculated shell side heat transfer coefficient (h_o) is too low, assume closer baffle

Spacing (B) close to 0.2 D_s and recalculate shell side heat transfer coefficient. However, this is subject to allowable pressure drop across the heat exchanger.

Step 8

Calculate % overdesign. Overdesign represents extra surface area provided beyond that required to compensate for fouling. Typical value of 10% or less is acceptable.

$$\%\ overdesign = \frac{A - A_{req}}{A_{req}} \times 100$$

Step 9

Calculate the tube-side pressure drop (ΔP_T):

(i) pressure drop in the straight section of the tube (frictional loss) (ΔP_t) and

(ii) Return loss (ΔP_{rt}) due to change of direction of fluid in a "multi-pass exchanger".

$\Delta P_T = \Delta P_t + \Delta P_{rt}$

Step 10

Calculate shell side pressure drop (ΔP_S): (i) pressure drop for flow across the tube bundle (frictional loss) (ΔP_s) and (ii) return loss (ΔP_{rs}) due to change of direction of fluid.

Total shell side pressure drop: $\Delta P_s = \Delta P_s + \Delta P_{rs}$

5. APPLICATIONS

One of the big advantages of using a shell and tube heat exchanger is that they often easy to service, particularly with models where floating tube bundle is available. One of the most common applications of shell and tube heat exchanger is the cooling of hydraulic fluids and oil in engines. They can also be used to cool or heat other mediums such as swimming pool water or charge air. It is also use in oil refineries, thermal power plants, chemical industries and many more.

6. LITERATURE REVIEW

Ahmerrais khan and sarfaraz khan focus on the various researches on Computational Fluid Dynamics (CFD) analysis in the field of heat exchanger. It has been found that CFD has been employed for the various areas of study in various types of heat exchanges Different turbulence models available in general purpose commercial CFD tools i.e. standard, realizable and RNG $k-\varepsilon$ RSM, and SST $k-\varepsilon$ in conjunction with velocity-pressure coupling schemes such as SIMPLE, SIMPLEC, PISO and etc. have been adopted to carry out the simulations. The quality of the solutions obtained from these simulations are largely within the acceptable range proving that CFD is an effective tool for predicting the behavior and performance of a wide variety of heat exchangers.

Philippe Wildi-Tremblay in his paper explains the procedure for minimizing the cost of a shell-and-tube heat exchanger based on genetic algorithms (GA). The global cost includes the operating cost (pumping power) and the initial cost expressed in terms of annuities. He took some geometrical parameters of the shell-and-tube heat exchanger as the design variables and the genetic algorithm is applied to solve the associated optimization problem. It is shown that for the case that the heat duty is given, not only can the optimization design increase the heat exchanger effectiveness significantly, but also decrease the pumping power dramatically.

SiminWangJianWenYanzhong Li in his paper shows that the configuration of a shell-and-tube heat exchanger was improved through the installation of sealers in the shell-side. The gaps between the baffle plates and shell is blocked by the sealers, which effectively decreases the short-circuit flow in the shell-side. The results of heat transfer experiments show that the shell-side heat transfer coefficient of the improved heat exchanger increased by 18.2–25.5%, the overall coefficient of heat transfer increased by 15.6–19.7%, and the efficiency increased by 12.9–14.1%. Pressure losses increased by 44.6–48.8% with the sealer installation, but the increment of required pump power can be neglected compared with the increment of heat flux. The heat transfer performance of the improved heat exchanger is intensified, which is an obvious benefit to the optimizing of heat exchanger design for energy conservation.

A.Pignotti in his paper established relationship between the effectiveness of two heat exchanger configurations which differ from each other in the inversion of either one of two fluids. This paper provides the way by which if the effectiveness of one combination is known in terms of heat capacity rate ratio and NTUs then the effectiveness of the other combination can be readily known.

V.K. Patel and R.V. Rao explores the use of a non-traditional optimization technique; called particle swarm optimization (PSO), for design optimization of shell-and-tube heat exchangers from economic view point. Minimization of total annual cost is considered as an objective function. Three design variables such as shell internal diameter, outer tube diameter and baffle spacing are considered for optimization. Two tube layouts viz. triangle and Square are also considered for optimization. Four different case studies are presented to demonstrate the effectiveness and accuracy of proposed algorithm. The results of optimization using PSO technique are compared with those obtained by using genetic algorithm (GA).

W.J.Marner, A.E.Bergles and J.M. Chenoweth studied the tubular enhanced surfaces used in shell-and-tube heat exchangers. As an initial step, the subject is limited to single-phase pressure drop and heat transfer; however, both tube side and shell side flows are taken into consideration. A comprehensive list of commercial augmented tubes which may be considered for use in shell-and-tube exchangers is given, along with a survey of the performance data which are available in the literature. They discussed the standardized data format which uses the inside and outside envelope diameters as the basis for presenting the various geometrical, flow, and heat transfer parameters for all tubular enhanced surfaces.

G.N. Xie, Q.W. Wang , M. Zeng, L.Q. Luo carried out an experimental system for investigation on performance of shell-and-tube heat exchangers, and limited experimental data is obtained. The ANN is applied to predict temperature differences and heat transfer rate for heat exchangers. BP algorithm is used to train and test the network. It is shown that the predicted results are close to experimental data by ANN approach. Comparison with correlation for prediction heat transfer rate shows ANN is superior to correlation, indicating that ANN technique is a suitable tool for use in the prediction of heat transfer rates than empirical correlations.

Hari Haran proposed a simplified model for the study of thermal analysis of shell and tube type heat exchangers of water and oil type is proposed. The robustness and medium weighted shape of Shell and Tube heat exchangers make them well suited for high pressure operations. This paper shows how to do the thermal analysis by using theoretical formulae and for this they have chosen a practical problem of counter flow shell and tube heat exchanger of water and oil type, by using the data that come from theoretical formulae they designed a model of shell and tube heat exchanger using Pro-E and done the thermal analysis by using ANSYS software and comparing the result that obtained from ANSYS software and theoretical formulae.

7. CONCLUSION

After the above paper it is easy to say that due to the unique shape, the shell & tube type heat exchanger finds use in high pressure application. It has given a great respect among all the classes of heat exchangers. Moreover well designed as well as described methods are available for its designing and analysis. The literature survey also shows the importance of this class of heat exchangers. Also by using Computational Fluid Dynamics or software like ANSYS we can secure the economy of time, material and effort.

ACKNOWLEDGEMENT

I am greatly indebted to my college BharatiVidyapeeth college of Engineering Navi Mumbai that has provided healthy environment to drive me to do this project and thankful to my management for their guidance.

NOMENCLATURE

T_1 Hot fluid inlet temperature
T_2 Hot fluid outlet temperature
t_1 Cold fluid inlet temperature
t_2 Cold fluid outlet temperature
D_s Inside shell diameter
P_t Pitch tube

n_t No of tubes

n_p Tentative no

F_t Correction factor

L Tube length

u Tube side fluid velocity

M, ρ, μ are mass flow rate, density and viscosity of tube side fluid

d_i Inner diameter

d_o Outer diameter

$U_{O,cal}$ Overall heat transfer coefficient based on outside tube area

$U_{O,assm}$ Assume a reasonable value of overall heat transfer coefficient

REFERENCES

[1] D. Q. Kern, "Process Heat Transfer", McGraw-Hill Book Company, Int. ed. 1965.
[2] V.K. Patel, R.V. Rao, "Design optimization of shell and tube heat exchanger using particle swarm optimization technique", Applied Thermal Engineering 30 (2010) 1417-1425.
[3] Hari Haran, Ravindra Reddy and Sreehari, "Thermal Analysis of Shell and Tube Heat ExChanger Using C and Ansys" , International Journal of Computer Trends and Technology (IJCTT) – volume 4 Issue 7–July 2013.
[4] A. Pignotti, "Relation Between the Thermal Effectiveness of Overall Parallel and Counter flow Heat Exchanger Geometries", J. Heat Transfer 111(2), 294-299 (May 01, 1989), asme.org.
[5] Indian Standard (IS: 4503-1967): Specification for Shell and Tube Type Heat Exchangers, BIS 2007, New Delhi.
[6] Wolverine Tube Heat Transfer Data Book.
[7] Dutta B.K. "Heat Transfer-Principles and Applications", PHI Pvt. Ltd., New Delhi, 1st ed. 2006.
Vindhya Vasiny Prasad Dubey, Raj RajatVerma, PiyushShankerVerma, A. K. Srivastava, "Steady State Thermal.
[8] Analysis of Shell and Tube Type Heat Exchanger To Demonstrate The Heat Transfer Capabilities Of Various Thermal Materials Using Ansys", Global Journals Inc., GJRE Volume 14, Issue 4, ISSN- 09755861.