International Journal of Education, Modern Management, Applied Science & Social Science (IJEMMASSS)
ISSN : 2581-9925, Impact Factor: 6.882, Volume 05, No. 01(III), January - March, 2023, pp. 221-232

STUDY OF HEAT EXCHANGERS DESIGN

Muskan Jain*
Ankita Kumari**
Priyanka Sati***
Depak Kumar****

ABSTRACT

With the great use in different chemical industries, heat exchangers are one of the utmost crucial heat transfer devices that are used to transfer or exchange the heat energy for different purposes. These are extremely significant and essential in the industrial recovery of heat among two process fluids. Although there are many other types of heat exchangers used in industries, shell and tube heat exchangers are the most significant and widely used. Hence, this review paper presents a compendium of various types and outlines about tube heat and shell exchanger, unlike ASME and TEMA standards, elementary design methods for two fluid heat exchanger, different alterations done in shell and tube heat exchanger for extra good performance in future use. In light of this, this paper provides a short-term background and research on various heat exchangers, focusing primarily on shell and tube heat exchangers.

Keywords: *Heat Exchangers, ASME and TEMA Standards, Modern Heat Exchanger, LMTD.*

Introduction

With a high competition in every field, the demand of smart work with skillful utilization is much more needed in the industrial sector as well. It became a major factor for engineers to make use of every bit of resources in useful and proper manner (4). Since for the proper utilization of energy resources becomes a challenge for the industrial sector, as these energy resources are very restricted and every sector of industry wants proper utilization of the basis. One key factor can also be concluded here that in earlier times, with a lack of information and knowledge, the industrial sector failed to utilize the sources properly and hence the result is coming today. However, the development of new technology and engineering field advancements enable the creation of devices that aid in resolving these problems. One of the gadgets could be used to use a source's heat energy. So, the device which helps in conveying heat among two or more fluids at different temperatures is known as heat exchangers (4) (1). In essence, there is typically no interaction between work and external heat in heat exchangers. Both heating and cooling processes use heat exchangers. Mostly used in refrigeration's, space heating, petrochemicals, chemical plants, gas processing and sewage treatments. A heat sink is an example of a conventional passive device that disperses heat from a mechanical device or electrical to a fluid medium, most frequently air or liquid coolant (1) (2).

But according to their flow pattern, heat exchangers would be distributed into three main categories. Grounded on their flow pattern, this heat exchanger uses parallel flow type. The parallel flow version of this heat exchanger has two fluids that enter at the same end and travel side by side to the other. The fluids enter it from opposing ends in the counterflow type. This design is the most efficient type of the heat exchanger. Additionally, in a heat exchanger with a cross flow design, the fluids pass through it perpendicular to one another (2) (4).

---

* Department of Chemical Engineering, Banasthali Vidyapith, Vanasthali, Rajasthan, India.
** Department of Chemistry, Banasthali Vidyapith, Vanasthali, Rajasthan, India.
*** Department of Chemistry, Banasthali Vidyapith, Vanasthali, Rajasthan, India.
**** Department of Chemical Engineering, Banasthali Vidyapith, Vanasthali, Rajasthan, India.

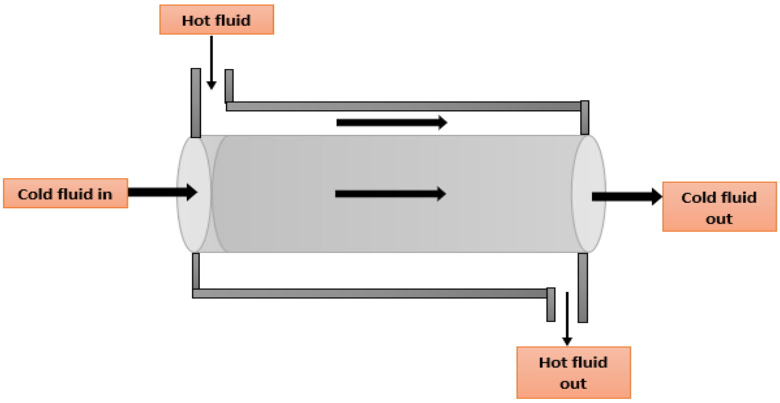

Figure 1: Parallel Flow HE

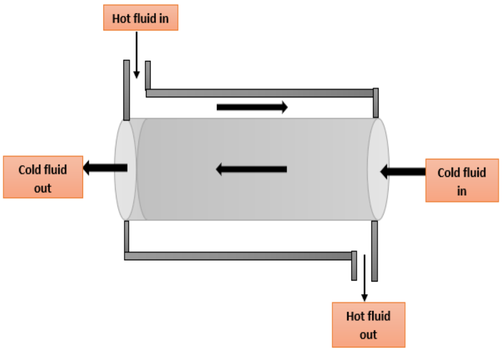

Figure 2: Counter Current Flow HE

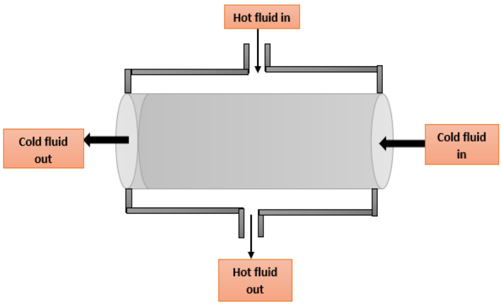

Figure 3: Cross flow HE

The transfer of heat occurs mainly in different ways i.e., conduction, convection and radiation. They are created to maximize the surface area of the wall between the two fluids and minimize the resistance to fluid flow through the heat exchanger in order to maximize efficiency (2).

There are three fundamental ways that heat is transferred, including:

- **Thermal Conduction:** Almost all processes involving heat transmission include conduction takes place. Heat is transferred through a body by the flow of electrons and small particle collisions known as thermal conduction (internal energy). Inorganic potential energy and microscopic kinetic energy - commonly referred to as internal energy-is imparted by the collisions of molecules, atoms, and electrons at the nanoscale. All states of matter, including liquids, solids, gases, and plasmas, can conduct.

- **Convection:** The process through which heat is transferred as a result of the large-scale movement of molecules inside gases, liquids, and molten rock. Advection, diffusion, or both can cause convection.
- **Radiation:** In a material medium or into space, radiation is the emission or transfer of energy as waves or particles. (2)

Varieties of Heat Exchanger

Numerous types of heat exchangers are offered by industrial sectors, each with its own design characteristics for the designing of heat exchangers as mentioned above. Most of them are:

- Double pipe Heat Exchanger
- Shell and Tube heat exchanger
- Plate Heat Exchanger
- Condensers, boilers and evaporators

The heat exchanger type that is utilised the most commonly among these is the shell and tube type.

Double Pipe Heat Exchanger

The most basic heat exchanger design and construction employed by twin pipe heat exchangers, a form of shell and tube heat exchanger, consists of two or more concentric, cylindrical pipes or tubes (one larger tube and one or more smaller tubes).

Twin pipe heat exchangers have design specifications that combine components due to its modular nature and ability to be employed in parallel, series, or series-parallel combinations within a system, double pipe heat exchangers provide some design flexibility. The modular use of twin pipe heat exchangers within a system in parallel, series, or series-parallel topologies provides some design flexibility.

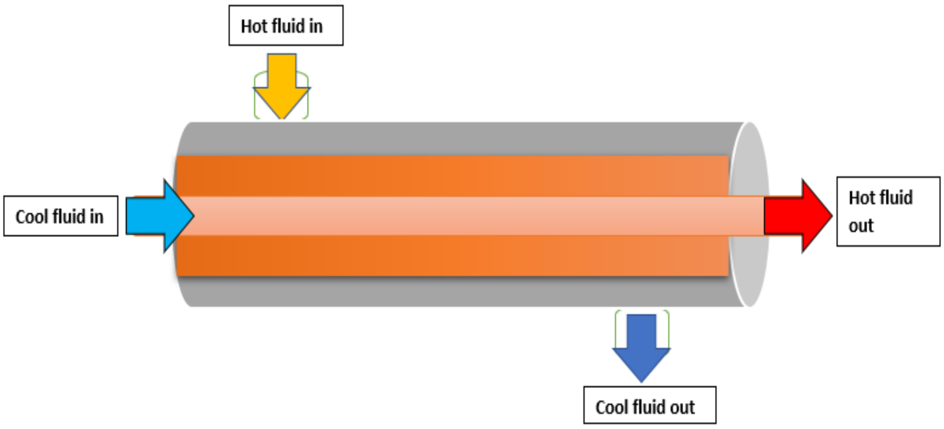

Figure 4: Double Pipe Heat Exchanger

Plate Heat Exchanger

Thin, corrugated plates are joined together to form plate heat exchangers, also known as plate type heat exchangers. One fluid can flow through each pair of plates, and when the pairs are stacked on top of one another and connected by bolts, welding or brazing, a second fluid-flowing passageway is created between the pairs.

Pillow or plate fin heat exchangers are just two examples of variations on the standard plate design. For better heat transfer over the plate surface, pillow plate exchangers pressurise the plates.

Shell and Tube Heat Exchanger

One of the most important and widely used types of heat exchangers in industry is the shell and tube heat exchanger. As suggested by the name, it is composed of a shell, which is typically a sizable pressure vessel with a number of tubes inside. A group of tubes—which might be simple, longitudinal, finned, etc.—is referred to as a "tube bundle." One set of tubes contains the fluid that must be heated or cooled, while the second set of tubes contains the fluid that passes over the first set of tubes to absorb or adsorb the necessary heat. Depending on the desired specifications, the fluids that flow in the heat exchanger can be liquids or gases. This makes it possible to recycle waste heat, which is a useful method of energy conservation. (2)(3)

The following are the shell and tube heat exchanger's four primary parts: -

- **Front Header or Stationary Header:** Exchanger's fluid enters here on tube side.
- **Rear Header:** The fluid either exits the exchanger's tube side or returns to the front header at this point.
- **Shell:** The tube bundle is inside.
- **Tube Bundle:** It contains of various things such as tubes, baffles, tie rods, tube sheets, etc. which holds the bundle together.

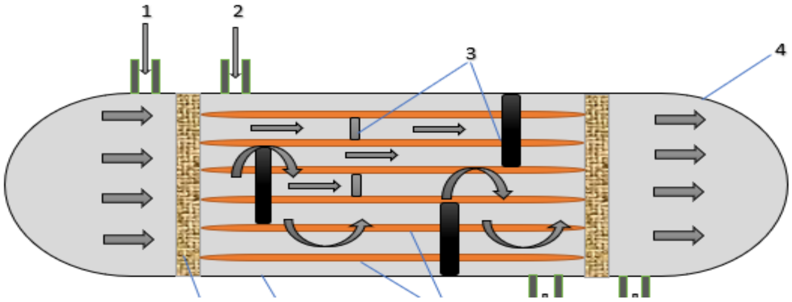

Figure 5: Design pattern of Shell & Tube HE

Figure 4 represents the design pattern of shell and tube heat exchanger where,

- Shell side fluid inlet
- Tube side fluid inlet
- Baffles
- Shell head
- Shell side fluid outlet
- Tube side fluid outlet
- Shell
- Tubes
- Tube plate

Condensers, Boilers and Evaporators

Heat exchangers that use two-phase heat transmission include condensers, evaporators, and boilers. As previously stated, during the heat transfer process in two-phase heat exchangers, one or more fluids change phases, either from a liquid to a gas or from a gas to a liquid.

Condensers, which exchange heat, cool a heated gas or vapour to the point of condensation, converting it from a gas or vapour to a liquid.

Various Classifications of Heat Exchanger

- **Indirect Contact Heat Exchanger**

Heat is continuously transmitted over an impermeable separating wall or temporarily into and out of a wall while fluid streams stay separate. But, in a perfect world, thermally interacting fluids don't immediately contact with one another. This kind of heat exchanger is also known as a storage type, direct transfer type and fluid-bed exchangers are further categories for surface heat exchangers.

- **Direct Contact Heat Exchanger**

In addition to heat transmission, direct-contact exchangers are frequently used for mass transfer processes including rectification and evaporative cooling. Applications requiring simply sensible heat transfer are uncommon. Moreover, a significant amount of the overall energy transfer in such an exchanger is made up by the enthalpy of phase shift. The rate of heat transfer often rises when a process is changed.

Efficiency of Heat Exchanger

There are several ways to characterise heat exchanger efficiency, and there are several key aspects of thermal performance to take into account:

- **Temperature Differential:** While building a heat exchanger, it is crucial to comprehend how coolant and hot fluid differ from one another. None the less, the coolant needs to warmer than the hot substance. More heat may be extracted from the hot fluid at higher coolant temperatures than at warmer ones. The same principle holds true for heat exchangers: if you have a glass of room temperature cold water, for instance, easier to chill off with ice than it is with just cool water.
- **Flow Rate:** The flow of fluids on the heat exchanger's primary and secondary sides is another important factor. Higher flow rates might enhance the exchanger's capacity to transfer heat, despite the fact that they typically produce larger densities, which may make it more challenging to remove energy, as well as higher velocity and pressure losses.
- **Installation:** Manufacturer's instructions can always be followed to attach the heat exchanger.

To make sure that the heat exchanger is still filled with water, coolant needs to be able to enter at the lowest point (depicted in the aforementioned diagrams). It's crucial to reflect the air flow when designing a cooler for air-cooled heat exchangers because any blocked areas in the centre will lower the cooling power.

Current Industrial Scenario

Heat is recovered between two process fluids using heat exchangers in industrial operations. Many companies today are looking for more rapid and effective substitutes for creating shell-and-tube heat exchangers. According to research in literature and the business world, Shell and tube heat exchanger needs efficient design solutions.

- **Thermal Design in Part A**

The STHE's thermal design takes into account process fluids on equally the shell and tube sides.

  - Choosing the necessary temperature requirements
  - Reducing the pressure drop on the shell and tube side
  - Restraining the side velocity of the tube and shell
  - Determining the fouling factor and heat transfer zone

- **Mechanical Design, Part B**
  - The TEMA [1-2] arrangement was chosen for the STHE's mechanical design based on thermal design.
  - Choosing the necessary temperature requirements
  - Reducing the pressure drop on the shell and tube side
  - Restraining the side velocity of the shell and tube
  - Determining the fouling factor and heat transfer zone
  - Figuring out the shell's diameter and baffle spacing upper and lower design constraints.

These pipes' horizontal axes are kept parallel to the shell. High pressure and high temperatures may be withstood because of the strength of the shell. Pumps are used to guide the flow of the fluids. One of the two fluids is permitted to travel through the shell, while the other is allowed to pass via pipe bundles. Instead of allowing the fluid in the shell to follow a straightforward course, various arrangements are used to make the flow convoluted.

By using baffles, fluid flow complexity is controlled. The pipes are likewise held by these baffles. Since there are several types of baffles and no set quantity, we can employ baffles as we see fit. In the shell, the baffles also support the pipes. We employ a variety of baffles:

Helical, double-segmental, de-resonating, helical and orifice baffles are some examples of baffles.

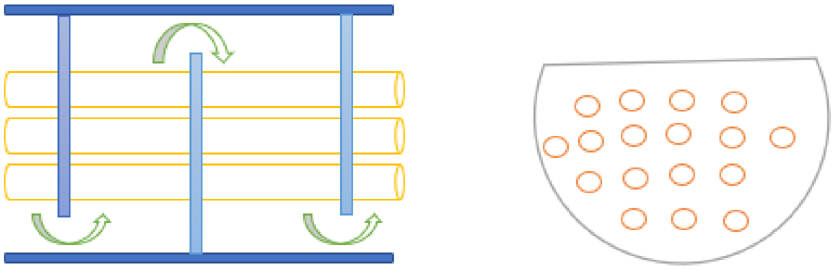

Figure 5a. Cut-Segmented Baffle

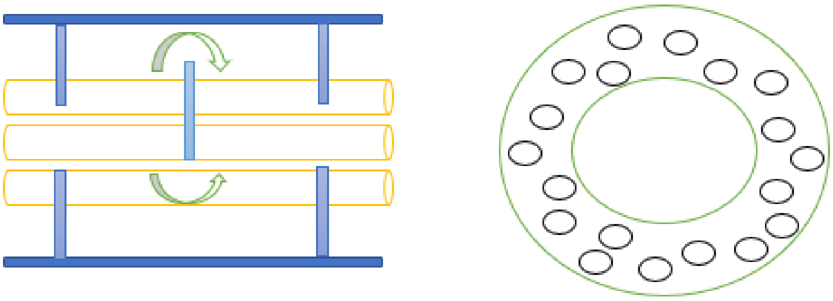

Figure 5b. Disc and Doughnut Baffle

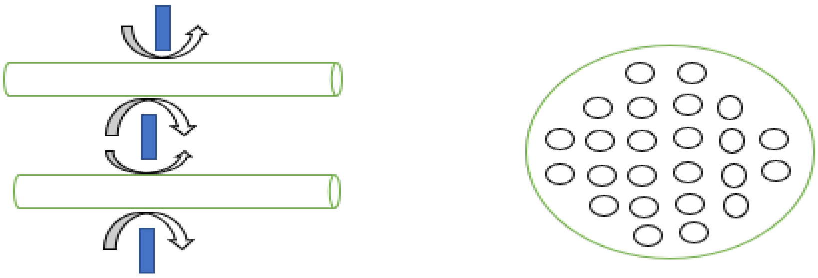

Figure 5c. Orifice Baffles

Thermal Design Considerations

The key factors used in the thermal design of heat exchangers are the speeds of hot and cold streams, the temperatures at which they terminate, and the fluid characteristics. The primary inputs for the thermal design of heat exchangers are the rates of hot and cold streams, their terminal temperatures, and fluid characteristics. Consider the following factors when designing a shell and tube heat exchanger: heat transfer area, number of tubes, length and diameter of the tubes, layout of the tubes, number of shell and tube passes, type of heat exchanger (removable tube bundle, fixed tube sheet etc.), number of baffles, tube pitch, shell and tube side pressure drop, type and size of the baffles, etc.

- **Shell**

It is important to choose the shell's diameter so the tube bundle fits snugly. The difference between the inner shell wall and the tube bundle exchanger determines the kind. The most common material used to construct shells is common steel tubing with an acceptable corrosion allowance. A 3/8-inch-thick shell with a shell ID of 12 to 24 inches can be used effectively with an operating pressure of 300 psi.

- **Tubes**

For small heat exchanger designs, the most common tube ODs are 3/4 and 1. The best environment for heat transfer is a shell with as many tubes as possible to rise turbulence. To withstand internal pressure and allow for acceptable corrosion, the tube's thickness must be sufficient. Birmingham Wire Gauge (BWG) and actual outer diameter are used to represent the tube thickness. The most popular tube lengths are 6, 8, 12, 16, and 20 feet. Longer tubes reduce shell diameter by increasing shell pressure drop. If a fluid penetrates the tube's shell side and has a low heat transfer coefficient, finned tubes are also employed. The most often used tube materials are bronze alloys, stainless steel copper, copper-nickel, and admiralty brass.

- **Tube Pitch, Tube Count and Tube Layout**

Tube pitch is the shortest distance between the centres of adjacent tubes. The tubes are frequently arranged in square or triangle patterns (pitch). The typical tube layouts are shown in the table below. The number of tubes that will fit into a given shell ID is determined by its tube count. The number of tubes relies on variables such as heat exchanger type, design pressure, shell ID, OD of tube, pitch, and arrangement.

- **Tube Passes**

To achieve a greater heat transfer coefficient and avoid the growth of scale, the number of passes needed to produce the necessary tube side fluid velocity must be calculated. 1 to 16 tube passes are available. The partition plate, which is a partition built into the exchanger head, is used to direct the tube side flow (also known as the pass partition).

Table 1: Tube Layouts

Tube OD, in	Pitch Type	Tube pitch, in
¾	Square	1
1		1 ¼
¾	Triangular	15/16
¾		1

- **Tube Sheet**

The tubes are joined together by tube sheets, which act as a barrier among the fluids inside the tubes and the shell. A backup plan should be in place in case the primary one fails. With "tube rolling," the tube sheet's wall has two or more grooves that are used to secure the tubes to the sheet. A superb, tight seal is created when the tube metal is pushed to migrate into the grooves. This is fastening system that large industrial exchangers most frequently use. To establish a tight seal, the tube sheet's thickness must be bigger than the tube's outer diameter.

- **Fouling Considerations during Designing of Heat Exchanger**

Most process fluids that are used in the exchanger contaminate the heat transfer surface. Due to oversizing, poor exchanger performance, and fouling, the cost of construction, additional energy use, and cleaning to remove deposited contaminants are all increased. To provide continuous service and to enable exchanger cleaning, a spare exchanger may be taken into account during design. When designing heat exchangers, the effect of fouling is considered by taking into account the shell side fouling resistances and tube side.

- **Selection of Fluids for Tube Side and Shell Side**

Fluid flow patterns on the shell side and tube side have big impact on heat exchanger's design. Table 2 provides some fundamental rules for fluid placement. It's critical to understand that these suggestions are not inflexible and that ideal fluid placement depends on a number of service-specific factors.

Table 2: Fluids Priority based on Shell and Tube Side

Fluids for Tube Side	Fluids for Shell Side
Cooling Water	Fluid with large temperature difference (>40℃)
Corrosive fluid	Condensing vapor (unless corrosive)
Less Viscous fluid	
Fouling water	
Hotter fluid	
High pressure steam	

Steps to follow during thermal designing procedure of shell and tube heat exchanger

They are typically designed in a trial-and-error calculations. Every basic step needs to be assumed according to the purpose, based on those further calculations has been made for thermal designing of shell and tube heat exchanger.

- **Step 1: Analysis of the Application**

The first thing we do when we get a request for a heat exchanger is analyse the application. Has the food industry found a use for it? Is it one used in industry? The design engineer must carefully specify the type of heat exchanger required to satisfy the requirements of the application.

It is necessary to provide the product and service fluids' design pressure, temperature, and maximum permissible pressure drop.

- **Step 2: Knowing the Fluid's Characteristics**

The following step is to analyse the fluids or gases involved, including the service side fluid and the product side fluid. There are four vital physical characteristics of the related fluids that must be understood: particular heat, density, viscosity, temperature sensitivity.

Design of heat exchanger will be more precise the more thoroughly we comprehend the physical characteristics of the relevant fluids.

- **Step 3: The Energy Balance**

Examining the energy balance comes next after accurately describing the physical characteristics. Typically, flow rate of the product and preferred entrance and exit temperatures are specified by the client. The third one may be identified after the previous two are understood.

- **Step 4: Determining the Heat Exchangers' Geometry**

At this point, the heat exchanger's geometry is determined by the design engineer. He will measure the length, diameter, wall thickness, and number of tubes in tube bundle as well as the shell diameter of the heat exchanger. Second, the measurements for the fluid connector sizes on the shell and tube sides are provided. Decision on applied materials must be taken at this time as well. Stainless steels are often used for the shell and tubes side of HRS Heat Exchangers, however other alloys may also be used.

- **Step 5: Thermal Analysis**

A thermal calculation is now done by the design engineer. The objective is to measure the heat transfer coefficients on both the shell and tube sides. These coefficients dependent on fluid’s velocity as well as the four main fluid characteristics. Using corrugated tubes requires a special formula developed for Heat Exchangers.

The overall heat transfer coefficient may be computed once the shell and tube side coefficients have been determined. The following phrase can be used to determine the needed area.

Area=Duty/[K×LMTD]

Where:

- **Area**: Required m2 of total heat transmission area.
- **Duty:** Total heat transmitted, in kcal per hour (derived from energy balance).
- **K:** [kcal/[hr.m2°C]] is the general heat transfer coefficient.
- **LMTD:** Log mean temperature difference, in degrees Celsius (the typical logarithmic difference in fluid temperatures between the shell and tube sides over the heat exchanger's length).

The pressure decreases for the fluids on the shell and tube sides are a crucial additional component. Laminar or turbulent flow, Reynolds number, surface abrasion of the outer shell, and surface abrasion of the inner tubes all affect the pressure drop.

- **Step 6: Interpreting the thermal calculation**

To evaluate if the pressure drops are within the design parameters, the calculated area is compared to the area provided in step four. The form of the heat exchanger must be changed, either by stretching it or by including inner tubes, if the computed area is more than the set area.

Repeat steps four through six as necessary to produce an acceptable design using the correct geometry.

- **Step 7: Calculations for Mechanical Design**

Mechanical design calculations must be carried out once the heat exchanger geometry has been defined to ensure that the heat exchanger is adequate for the design pressure and circumstances. The following are examples of calculations:

- calculating the thickness of the shell wall.
- calculating the thickness of the nozzle wall.
- inner tube wall thickness calculation.
- calculating the size of the expansion joint (to account for shell and tube side temperature-related differential expansion).
- calculating the thickness of a tube sheet.

It's possible that the wall thicknesses or other parameters generated by the mechanical design calculations won't match the geometrical design specified in step 4. It is necessary to create a new geometry proposal and repeat steps 4 through 7 as needed.

- **Step 8: Making the Manufacturing Drawings**

The manufacturing drawings may be created once all of the heat exchanger's dimensions have been established. Details on the different heat exchanger parts, such as the shell, tubes, expansion joints, connectors, etc., are included in the drawing package.

Governing Equations for Designing Shell and Tube Heat Exchanger

The steps which needs to be followed on applying the governing equations.

- Review all the thermophysical properties as provided by the customer (fluid required for the heat exchanger, at what temperature, any physical property provided, pressure drop etc.)
- Calculate average temperature for both tube and shell side fluid.
- Perform **tube side** calculations.
  - Heat Duty or Energy Balance

$$Q = \dot{m}_s \times c_p \times \Delta T$$

  - According to the requirement, calculate number of passes.
  - Determine LMTD

$$\text{LMTD} = \frac{\Delta th - \Delta tc}{\ln\left(\frac{\Delta th}{\Delta tc}\right)} = \frac{(T1 - t2) - (T2 - t1)}{\ln\left(\frac{T1 - t2}{T2 - t1}\right)}$$

t_1: inlet temperature of cold fluid

t_2:outlet temperature of cold fluid

T_1: inlet temperature of hot fluid

T_2: outlet temperature of hot fluid

  - Determine correction factor (Ft)

$$F_T = \frac{\sqrt{R^2+1}\,\ln\left(\frac{1-S}{1-RS}\right)}{(R-1)\ln\left\{\frac{2-S(R+1-\sqrt{R^2}+1)}{2-S(R+1+\sqrt{R^2}+1)}\right\}}$$

Where,

$$R = \frac{T1 - T2}{t2 - t1} \text{ and } S = \frac{t2 - t1}{T1 - t1}$$

Here, R and S are caloric temperatures.

  - Assume overall heat transfer coefficient, according to the requirement.
  - Calculate heat transfer area.

$$A = \frac{Q}{U_{0assm} \times LMTD \times F_T}$$

  - Based on requirement, assume tube size.
  - Calculate number of tubes.

$$N_t = \frac{A}{\pi \times do,t \times Lt}$$

- Calculate cross sectional area of one tube.

$\frac{1}{4}\pi \times (d_{i,t})^2$

- Calculate tube per pass.
- Calculate total flow area in one pass
- As per requirement, assume tube pitch.
- Calculate Reynolds number.
- As per value, calibrate Colburn factor.
- Calculate heat transfer coefficient.

$$h_i = \left(\frac{j_h k}{Di_t}\right)\left(\frac{C_u}{k}\right)^{1/3}\left(\frac{\mu}{\mu_\omega}\right)^{0.14}$$

- Calculate fouling factor for inner and outer surfaces, thermal conductivity, wall resistances, etc.

Perform Shell side Calculations

- Calculate tube pitch, shell ID.
- Calculate Clearance.
- Calculate baffle spacing.
- Calculate Reynolds number for shell side.
- Calculate Colburn factor for shell side.
- Calculate heat transfer coefficient for shell side.
- Calculate fouling factor for shell side.
- Calculate overall heat transfer coefficient.
- Calculate pressure drop in both shell and tube side.

Conclusion

Many types of heat exchangers used in industry are discussed in this paper, along with the criteria for choosing a device based on performance, function, and cost. They are constructed as condensers, evaporators, or heaters depending on the process conditions.

After discovering the many industrial applications of shell and tube heat exchangers, several academics chose to concentrate their research on these devices. These heat exchangers' performance was enhanced by changing several parameters using computational and experimental simulations. Baffle spacing, baffles, tube diameter, baffle angles, working fluid, and other characteristics were also taken into consideration. Shell and tube heat exchangers must be made less costly and more effective in order to be used for the purposes intended. A number of aspects of shell and tube heat exchangers could use more research. As a result, baffles might receive a lot of attention. The efficiency of the heat exchanger for counter-current flow can also reach 1 in ideal conditions. However, in the case of parallel flow, the heat exchanger's efficiency should be less than 1.

The exchanger's initial operation is taken into consideration in the first stage. The second step takes growing pressure loss into account, if it is possible, in exchangers with single-phase heat transfer.

Higher heat transfer coefficients are produced by increased velocity, which could be enough to boost performance. Secondly, a critical assessment of the predicted fouling variables needs to be taken into account. By performing routine cleanings and using less conservative fouling agents, heat exchanger performance can be improved.

References

1 Lunsford, K. M. (1998). Increasing heat exchanger performance. *Hydrocarbon engineering*, *77*, 786-793.

2 Ibrahim, H. A. (2012). Fouling in heat exchangers. *MATLAB-A fundamental tool for scientific computing and engineering applications*, *3*, 57-96.

3 Anand, R. S., David, S., Gajendiran, M., & Stanley, K. (2020, August). Design and analysis of shell and tube heat exchanger for low temperature applications using CFD. In *IOP Conference Series: Materials Science and Engineering* (Vol. 912, No. 4, p. 042056). IOP Publishing.

4 Sharma, V. K., & Kumar, S. Improved Shell and Tube Heat Exchanger (STHX) Customized using a variety of Baffle Arrangements: A Review.

5 Dubey, V. V. P., Verma, R. R., & Verma, P. S. AK Srivastava ''Performance Analysis of Shell & Tube Type Heat Exchanger under the Effect of Varied Operating Conditions e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 11, Issue 3 Ver. VI, May-Jun. 2014. *IOSR Journal of Mechanical and Civil Engineering*, 08-17.

6 Silaipillayarputhur, K., & Khurshid, H. (2019). The design of shell and tube heat exchangers–A review. *International Journal of Mechanical and Production Engineering Research and Development*, *9*(1), 87-102.

7 Patel, S. K., & Mavani, A. M. (2012). Shell and tube heat exchanger thermal design with optimization of mass flow rate and baffle spacing. *International Journal of advanced engineering research and studies*, *2*(1), 130-135.

8 Dubey, V. V. P., Verma, R. R., Verma, P. S., & Srivastava, A. K. (2014). Performance analysis of shell & tube type heat exchanger under the effect of varied operating conditions. *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, *11*(3), 08-17.

9 TEMA, "Standards of the Tubular Exchanger Manufacturer's Association [TEMA]," 8th Edition, Section 1-5.

10 R. K. Shah, "Fundamentals of Heat Exchanger Design," 2nd Edition, Chapter 1-5, Wiley, Hoboken, 2003.

11 R. Mukherjee, "Practical Thermal Design of Shell and Heat Exchangers," 2nd Edition, Chapter 1-5, 8 Begell House, Redding, 2004.

12 Deshpande, S. S., & Hinge, S. A. (2014). Design and performance study of shell and tube heat exchanger with single segmental baffle having perpendicular & parallel-cut orientation. *Int. J. Eng. Res. Technol.*, 1-5.

13 Gireesh, D., & Rao, J. B. (2017). Design and analysis of heat exchanger with different baffles. *Int. J. Mag. Eng. Technol. Manag. Res.*, 1-12.

14 Bichkar, P., Dandgaval, O., Dalvi, P., Godase, R., & Dey, T. (2018). Study of shell and tube heat exchanger with the effect of types of baffles. *Procedia Manufacturing*, *20*, 195-200.

15 Prasad, A. K., & Anand, K. (2020). Design Analysis of Shell Tube Type Heat Exchanger. *Int. J. Eng. Res. Technol*, *9*(01).

16 Cahya, A. H., & Permatasari, R. (2020). Design of shell and tube heat exchanger for waste water using heat transfer research inc. *Int. J. Adv. Sci. Technol.*, 611-622.

17 Wang, Q., Chen, Q., Chen, G., & Zeng, M. (2009). Numerical investigation on combined multiple shell-pass shell-and-tube heat exchanger with continuous helical baffles. *International Journal of Heat and Mass Transfer*, *52*(5-6), 1214-1222.

18 Zhang, J. F., He, Y. L., & Tao, W. Q. (2009). 3D numerical simulation on shell-and-tube heat exchangers with middle-overlapped helical baffles and continuous baffles–Part I: Numerical model and results of whole heat exchanger with middle-overlapped helical baffles. *International Journal of Heat and Mass Transfer*, *52*(23-24), 5371-5380.

19 Abd, A. A., Kareem, M. Q., & Naji, S. Z. (2018). Performance analysis of shell and tube heat exchanger: Parametric study. *Case studies in thermal engineering*, *12*, 563-568.

20 Krishnan, N., Suresh, M., & Kumar, B. (2016). An overview on shell and tube heat exchanger. *Int. J. Eng. Sci. Comput.*, 2632-2636.

21 Buonomo, B., di Pasqua, A., Ercole, D., & Manca, O. (2018). Numerical investigation on a heat exchanger in aluminium foam. *Energy Procedia*, *148*, 782-789.

22 Parmar, K., Gora, O., Desai, K., & Mehta, N. (2017). A Practical Attempt to Improve Performance of Heat Exchanger. *International Journal of Advance Research and Innovative Ideas in Education, ISSN*, 2395-4396.

23 Sinnott, R. K., Coulson, J. M., & Richardson, J. F. (2005). *Chemical engineering design* (Vol. 6, No. 4). Oxford: Elsevier Butterworth-Heinemann.

24 Kern, D. Q. (1965). Process Heat Transfer, Mc Graw-Hi. *Book Company, New York*.

25 Rasik, M. M., Kuldeep, M., Poojan, G., Dungrani, A., Mitrajsinh, G., Dhvanit, D., ... & Rajan, G. To Increase the Efficiency of Heat exchanger by Modification in its Proper Design. *Journal homepage: www. ijrpr. com ISSN*, *2582*, 7421.

26 Couper, J. R., Penney, W. R., Fair, J. R., & Walas, S. M. (2005). *Chemical process equipment: selection and design*. Gulf professional publishing.

27 Saltzman, D. J., Bichnevicius, M., Lynch, S. P., Simpson, T., Reutzel, T., Dickman, C., & Martukanitz, R. (2017). Experimental comparison of a traditionally built versus additively manufactured aircraft heat exchanger. In *55th AIAA Aerospace Sciences Meeting* (p. 0902).

28 Haran, H., & Reddy, R. (2013). Sreehari, “Thermal Analysis of Shell and Tube Heat Exchanger Using C and Ansys”. *International Journal of Computer Trends and Technology (IJCTT)–volume*, *4*.

29 Patel, V. K., & Rao, R. V. (2010). Design optimization of shell-and-tube heat exchanger using particle swarm optimization technique. *Applied Thermal Engineering*, *30*(11-12), 1417-1425.

30 Pignotti, A. (1989). Relation between the thermal effectiveness of overall parallel and counterflow heat exchanger geometries.

31 Mukharji, R. (1988). Effective design of shell and tube heat exchanger. *American Institute of Chemical Engineering*, *3*(11), 17200-17204.

32 Taborek, J. (1979). Evolution of heat exchanger design techniques. *Heat Transfer Engineering*, *1*(1), 15-29.

33 Incropera, F. P., & DeWitt, D. P. (2002). Fundamentals of Heat and Mass Transfer 5th Ed Wiley. *New York*.

34 Serna, M., & Jiménez, A. (2005). A compact formulation of the Bell–Delaware method for heat exchanger design and optimization. *Chemical Engineering Research and Design*, *83*(5), 539-550.

35 Shah, R. K., & Sekulic, D. P. (2003). *Fundamentals of heat exchanger design*. John Wiley & Sons.

❖◆❖