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Modern Heat Exchanger - A Review

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Abstract

Heat exchangers are one of the most important heat transfer apparatus that find its use in industries like oil refining, chemical engineering, electric power generation etc. Shell-and-tube type of heat exchangers have been commonly and most effectively used in Industries over the years. In this paper we see a review of Outline and Types of Heat exchangers , Thermal Design and Mechanical Design by the use of ASME,TEMA standard take a case study of Modern Shell & Tube type Heat exchanger

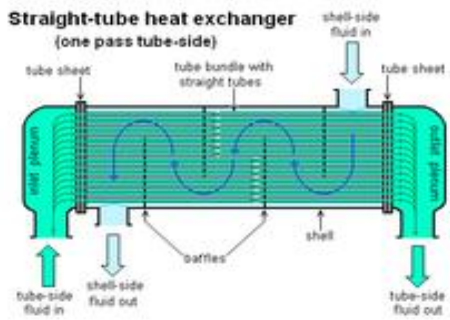
Keywords—Modern Heat exchanger, Shell and Tube heat exchanger, Thermal Design, Mechanical Design, HTRI Software.

1.Introduction—A heat exchanger is a device that is used to transfer thermal energy between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact. In heat exchangers, there are usually no external heat and work interactions. Typical applications involve heating or cooling of a fluid stream of concern and evaporation or condensation of single or multi component fluid streams. In other applications, the objective may be to recover or reject heat, or sterilize, pasteurize, fractionate, distill, concentrate, crystallize, or control a process fluid. In a few heat exchangers, the fluids exchanging heat are in direct contact. In most heat exchangers, heat transfer between fluids takes place through a separating wall or into and out of a wall in a transient manner. In many heat exchangers, the fluids are separated by a heat transfer surface, and ideally they do not mix or leak. Such exchangers are referred to as direct transfer type, or simply recuperators. In contrast, exchangers in which there is intermittent heat exchange between the hot and cold fluids—via thermal energy storage and release through the exchanger surface or matrix—are referred to as indirect transfer type, or simply regenerators. Such exchangers usually have fluid leakage from one fluid stream to the other, due to pressure differences and matrix rotation/valve switching. Common examples of heat exchangers are shell-and tube exchangers, automobile radiators, condensers, evaporators, air preheaters, and cooling towers. If no phase change occurs in any of the fluids in the exchanger, it is sometimes referred to as a sensible heat exchanger. There could be internal thermal energy sources in the exchangers, such as in electric heaters and nuclear fuel elements. Combustion and chemical reaction may take place within the exchanger, such as in boilers, fired heaters, and fluidized-bed exchangers. Mechanical devices may be used in some exchangers such as in scraped surface exchangers, agitated vessels, and stirred tank reactors.

A heat exchanger is a piece of equipment built for efficient heat transfer from one medium to another. The media may be separated by a solid wall, so that they never mix, or they may be in direct contact. They are widely used in space heating, refrigeration, air conditioning , power plants, chemical plants, petrochemical plants, petroleum refineries, natural gas processing, and sewage treatment. The classic example of a heat exchanger is found in an internal combustion engine in which a circulating fluid known as engine coolant flows through radiator coils and air flows past the coils, which cools the coolant and heats the incoming air.

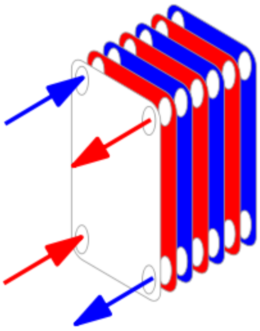
2. Types of heat exchangers—

1) Shell and tube heat exchanger



Shell and tube heat exchangers consist of a series of tubes. One set of these tubes contains the fluid that must be either heated or cooled. The second fluid runs over the tubes that are being heated or cooled so that it can either provide the heat or absorb the heat required. A set of tubes is called the tube bundle and can be made up of several types of tubes: plain, longitudinally finned, etc. Shell and tube heat exchangers are typically used for high-pressure applications (with pressures greater than 30 bar and temperatures greater than 260 °C). This is because the shell and tube heat exchangers are robust due to their shape.

2) Conceptual diagram of a plate and frame heat exchanger.



3) Single plate heat exchanger

Another type of heat exchanger is the plate heat exchanger. One is composed of multiple, thin, slightly separated plates that have very large surface areas and fluid flow passages for heat transfer. This stacked-plate arrangement can be more effective, in a given space, than the shell and tube heat exchanger. Advances in gasket and brazing technology have made the plate-type heat exchanger increasingly practical. In HVAC applications, large heat exchangers of this type are called plate-and-frame; when used in open loops, these heat exchangers are normally of the gasket type to allow periodic disassembly, cleaning, and inspection

4) Plate and shell heat exchanger

A third type of heat exchanger is a plate and shell heat exchanger, which combines plate heat exchanger with shell and tube heat exchanger technologies. The heart of the heat exchanger contains a fully welded circular plate pack made by pressing and cutting round plates and welding them together. Nozzles carry flow in and out of the platepack (the 'Plate side' flow path).The fully welded platepack is assembled into an outer shell that creates a second flow path (the 'Shell side'). Plate and shell technology offers high heat transfer, high pressure, high operating temperature, compact size, low fouling and close approach temperature. In particular, it does completely without gaskets, which provides security against leakage at high pressures and temperatures.

5) Adiabatic wheel heat exchanger

This type of heat exchanger uses an intermediate fluid or solid store to hold heat, which is then moved to the other side of the heat exchanger to be released. Two examples of this are adiabatic wheels, which consist of a large wheel with fine threads rotating through the hot and cold fluids, and fluid heat exchangers.

6) Plate fin heat exchanger

This type of heat exchanger uses "sandwiched" passages containing fins to increase the effectively of the unit. The designs include cross flow and counter flow coupled with various fin configurations such as straight fins, offset fins and wavy fins. Plate and fin heat exchangers are usually made of aluminium alloys, which provide high heat transfer efficiency. The material enables the system to operate at a lower temperature and reduce the weight of the equipment. Plate and fin heat exchangers are mostly used for low temperature services such as natural gas, helium and oxygen liquefaction plants, air separation plants and transport industries such as motor and aircraft engines .Advantages of plate and fin heat exchangers: High heat transfer efficiency especially in gas treatment Larger heat transfer area Approximately 5 times lighter in weight than that of shell and tube heat exchanger. Able to withstand high pressure

7) Pillow plate heat exchanger

A pillow plate exchanger is commonly used in the dairy industry for cooling milk in large direct-expansion stainless steel bulk tanks. The pillow plate allows for cooling across nearly the entire surface area of the tank, without gaps that would occur between pipes welded to the exterior of the tank. The pillow plate is constructed using a thin sheet of metal spot-welded to the surface of another thicker sheet of metal. The thin plate is welded in a regular pattern of dots or with a serpentine pattern of weld lines. After welding the enclosed space is pressurized with sufficient force to cause the thin metal to bulge out around the welds, providing a space for heat exchanger liquids to flow, and creating a characteristic appearance of a swelled pillow formed out of metal.

8) Fluid heat exchangers

This is a heat exchanger with a gas passing upwards through a shower of fluid (often water), and the fluid is then taken elsewhere before being cooled. This is commonly used for cooling gases whilst also removing certain impurities, thus solving two problems at once. It is widely used in espresso machines as an energy-saving method of cooling super-heated water to use in the extraction of espresso.

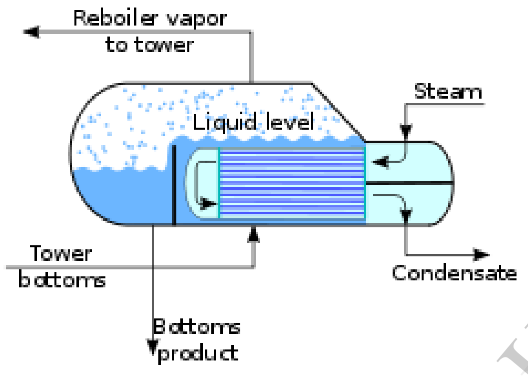
9) Waste heat recovery units

A Waste Heat Recovery Unit (WHRU) is a heat exchanger that recovers heat from a hot gas stream while transferring it to a working medium, typically water or oils. The hot gas stream can be the exhaust gas from a gas turbine or a diesel engine or a waste gas from industry or refinery.

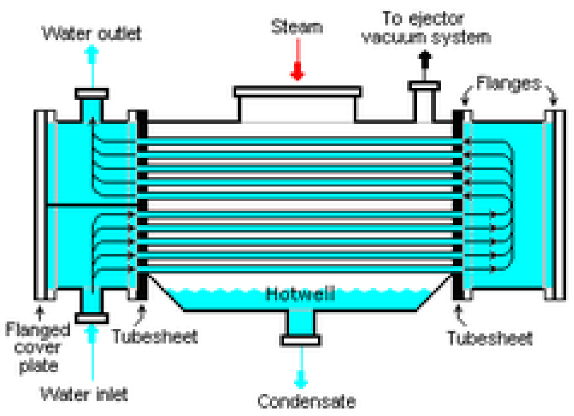
10) Dynamic scraped surface heat exchanger

Another type of heat exchanger is called "(dynamic) scraped surface heat exchanger". This is mainly used for heating or cooling with high-viscosity products, crystallization processes, evaporation and high-fouling applications. Long running times are achieved due to the continuous scraping of the surface, thus avoiding fouling and achieving a sustainable heat transfer rate during the process.

11) Phase-change heat exchangers



Typical kettle reboiler used for industrial distillation towers



12) Typical water-cooled surface condenser

In addition to heating up or cooling down fluids in just a single phase, heat exchangers can be used either to heat a liquid to evaporate (or boil) it or used as condensers to cool a vapour and condense it to a liquid. In chemical plants and refineries, reboilers used to heat incoming feed for distillation towers are often heat exchangers. Distillation set-ups typically use condensers to condense distillate vapours back into liquid. Power that use steam-driven turbines commonly use heat exchangers to boil water into steam. Heat exchangers or similar units for producing steam from water are often called boilers or steam generators. In the nuclear power plants called pressurized water reactors, special large heat exchangers pass heat from the primary (reactor plant) system to the secondary (steam plant) system, producing steam from water in the process. These are called steam generators. All fossil-fueled and nuclear power plants using steam-driven turbines have surface condensers to convert the exhaust steam from the turbines into condensate (water) for re-use. To conserve energy and cooling capacity in chemical and other plants, regenerative heat exchangers can transfer heat from a stream that must be cooled to another stream that must be heated, such as distillate cooling and reboiler feed pre-heating.This term can also refer to heat exchangers that contain a material within their structure that has a change of phase. This is usually a solid to liquid phase due to the small volume difference between these states. This change of phase effectively acts as a buffer because it occurs at a constant temperature but still allows for the heat exchanger to accept additional heat. One example where this has been investigated is for use in high power aircraft electronics.

Various classification of Heat Exchangers

Classification of heat exchangers according to transfer processes

Indirect-Contact Heat Exchangers

The fluid streams remain separate and the heat transfers continuously through an impervious dividing wall or into and out of a wall in a transient manner. Thus, ideally, there is no direct contact between thermally interacting fluids. This type of heat exchanger, also referred to as a surface heat exchanger, can be further classified into direct-transfer type, storage type, and fluidized-bed exchangers.

Direct-Contact Heat Exchangers

In a direct-contact exchanger[1], two fluid streams come into direct contact, exchange heat, and are then separated. Common applications of a direct-contact exchanger involve mass transfer in addition to heat transfer, such as in evaporative cooling and rectification; applications involving only sensible heat transfer are rare. The enthalpy of phase change in such an exchanger generally represents a significant portion of the total energy transfer. The phase change generally enhances the heat transfer rate. Compared to indirect contact recuperators and regenerators, in direct-contact heat exchangers: very high heat transfer rates are achievable the exchanger construction is relatively inexpensive the fouling problem is generally non existent, due to the absence of a heat

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transfer surface (wall) between the two fluids. However, the applications are limited to those cases where a direct contact of two fluid streams is permissible.

Existing Industrial Scenario

In industries, heat exchangers are used in industrial process to recover heat between two process fluids. Shell-and-tube heat exchangers are the most widely used heat exchangers in process industries because of their relatively simple manufacturing and their adaptability to different operating conditions. But nowadays numbers of industries are searching for effective and less time consuming alternatives of designing of shell-and-tube heat exchangers. As per literature and industrial survey it is observed that there is need of effective design options for STHE.

Part A—Thermal Design

The thermal design of STHE includes;

1) Consideration of process fluids in both shell and tube side
2) Selection of required temperature specifications
3) Limiting the shell and tube side pressure drop
4) Setting shell and tube side velocity limits
5) Finding heat transfer area including fouling factor

Part B—Mechanical Design

The mechanical design of STHE includes;

1) Selection of TEMA[1-2] layout—based on thermal design.
2) Selection of required temperature specifications
3) Limiting the shell and tube side pressure drop
4) *Setting* shell and tube side velocity limits
5) Finding heat transfer area including fouling factor
6) Setting upper and lower design limits on shell diameter and baffle spacing

As per literature and industrial survey at [A_1 & A_2] the design is carried out using in-house developed software for design and drafting. This dedicated software enables qualified engineers to accomplish complex design calculations complying strictly with the requisite international codes and standards. The software also generates fabrication drawings to scale and 3-D images of the Exchanger thereby giving warning of any foul-up/mis-match in nozzles, RF-Pads and in the dimensions of various components. Also an experienced team of design engineers undertakes thermal and mechanical design of complex heat exchangers and generate fabrication drawings to scale along with weights and estimates based on customer's specifications. These designs are optimized to arrive at an optimal size. After carrying out the design, the final output is in an AutoCAD drawing format (DWG) or DWF (Web format).

In this proposed work design, development & testing of STHE is carried out. Along with the parameter considered as per [A1 & A2], the software generated design was cross checked with manual design. Also vibration analysis is performed to optimize unsupported span of tube by using HTRI software.

3. Problem Definition & Objective

The problem presented in this paper is to design & develop a STHE, conforming to the TEMA/ASME [1-2] Standards, based on following Input Data:

1) Inlet & Outlet Temperatures of fluids on Shell & Tube Side is to perform thermal and mechanical design of STHE using TEMA/ASME standards to reduce time.

4. Design of STHE

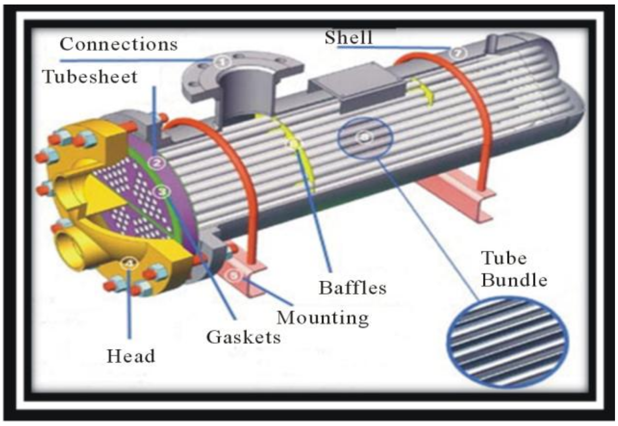
The design of STHE involves a large number of geometric and operating variables as a part of the search for an exchanger geometry that meets the heat duty requirement and a given set of design constrains. Usually a reference geometric configuration of the equipment is chosen at first and an allowable pressure drop value is fixed. Then, the values of the design variables are defined based on the design specifications and the assumption of several mechanical and thermodynamic parameters in order to have a satisfactory heat transfer coefficient leading to a suitable utilization of the heat exchange surface. The designer's choices are then verified based on iterative procedures involving many trials until a reasonable design is obtained which meets design specifications with a satisfying compromise between pressure drops and thermal exchange performances [4].

The details of STHE are shown in **Table 1**. **Figure 1** shows the various major components of a typical STHE as listed below:[1-6]

Table 1. STHE specification.

Parameter	Description
Size (Dia./length)	Ø1336/10,000 mm
Surface area (eff.)/unit	781.4 m. sq.
Shells/unit	1
Heat exchanged, (*Q*)	5064.9 KW
LMTD (Corrected)	9.15˚C

Figure 1. Major components of a typical STHE.



1) Connections
2) Tube Sheet
3) Gasket
4) Head/Dish End
5) Mounting/Support
6) Baffles
7) Shell
8) Tube Bundle

4.1. Part-A: Thermal Design

Design input:

1) Mass flow rate (m)
2) Heat exchanged (Q)
3) Shell side inlet temperature (t_{si})
4) Shell side outside temperature (t_{so})
5) Tube side inlet temperature (t_{ti})
6) Tube side outlet temperature (t_{to})
7) Transfer rate (U)
8) Tube outside diameter (d_o)
9) Length of tube (L)

Output:

1) LMTD (Log Mean Temp. Difference) (θ_m):

(θ_m) =(θ_1- θ_2(ln((θ_1)/ (θ_2)) (

$$= \left(t_{si} - t_{ti}\right) - \left(t_{so} - t_{to}\right) / \ln\left(\left(t_{si} - t_{ti}\right) / \left(t_{so} - t_{to}\right)\right)$$

$$= 9.15°C$$

2) Area (A):

$$Q = U \times A \times \theta_m \quad \text{where, } A = 781.61 \text{ m}^2$$

3) Number of Tubes (n): in mm,

$$Q = U \times n \times \pi \times d_o \times L \times \Delta_t \text{ where,}$$

- Max. allowable pressure, new and cold

$$= \left(2 \times S \times E \times t\right) / \left(K \times D + 0.2 \times t\right) = 10 \text{ bar}$$

- Actual stress at given pressure and thickness,

$$= \left(P_s \times R\right) / \left(S \times E - 0.6 \times P_s\right) = 4.94 \text{ N/mm}^2$$

- Straight flange maximum allowable working pressure:

$$= \left(S \times E \times t\right) / \left(R + 0.6 \times t\right) = 9.27 \text{ bar}$$

Design under external pressure:

- Maximum allowable external pressure (MAEP):

$$\text{MAEP} = B / \left(K_o \times D_{so} / t\right) = 2.76 \text{ bar}$$

Tube Design

Design input:

- Internal Design Pressure (Pt)
- Allowable stress at design Temperature (S)
- Outside diameter (D_o)
- Joint efficiency for Longitudinal joint (E)

Output:

- Required Tube Thickness:

$$T_{rt1} = P_t \times D_o / 2 \; S \times E \; + \; 0.4 \times P_t \; = 1.24 \text{ mm}$$

Baffles and Spacing

- Baffle type: Triple segmental
- Nominal shell ID: 1336 mm
- Baffle spacing (Min.): segmental baffles should not be spaced closer than 1/5th of the shell ID or 2"

4.2. Part-B: Mechanical Design

Main Shell Design

Design Input:

1) Internal design pressure (P_s)
2) External design pressure (P_e)
3) Shell outside diameter (D)
4) Joint efficiency for longitudinal joint (K)

5) Joint efficiency for circumferential joint (E)
6) Allowable Stress (S)
7) Element thickness (t)
8) Joint efficiency for outer longitudinal joint (K_o)
9) Shell outside diameter with allowance (D_{so})
10) Constant Factor (B)
$n = 660$ tubes

whichever greater. However, special design considerations may dictate a closer spacing.

- Baffle spacing (center to center) = 570 mm
- Spacing at inlet = 670.67 mm
- Baffle thickness = 12.7 mm

Output:

Design under Internal Pressure:

- Required thickness due to internal pressure (t_r):

$$=(P_s \times D \times K) / (2 \times S \times E - 0.2 \times P_s) = 4.92 \text{ mm}$$

- Max. allowable working pressure at given thickness

$$=(2 \times S \times E \times t) / (K \times D + 0.2 \times t) = 7.99 \text{ bar}$$

- Nominal shell ID: 1336 mm.
- Baffle spacing (center to center) = 570 mm.
- Spacing at inlet = 670.67 mm.
- Baffle thickness = 12.7 mm.

Litrature Review:

As per literature and industrial survey at [A_1 & A_2] the design is carried out using in-house developed software for design and drafting. This dedicated software enables qualified engineers to accomplish complex design calculations complying strictly with the requisite international codes and standards. the dimensions of various components. Also an experienced team of design engineers undertakes thermal and mechanical design of complex heat exchangers and generate fabrication drawings to scale along with weights and estimates based on customer's specifications. These designs are optimized to arrive at an optimal size. After carrying out the design, the final output is in an AutoCAD drawing format (DWG) or DWF (Web format).

Conclusion

The design of STHE *i.e.* thermal and mechanical design was carried out using TEMA/ASME standards both manually and using software. It is found that design of STHE obtained by both approaches is very easy, simple advance & less time consuming as modern heat exchanger.

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