

General Description

Shell and Tube Heat Exchangers are one of the most popular types of exchanger due to the flexibility the designer has to allow for a wide range of pressures and temperatures.

There are two main categories of **Shell and Tube exchanger**:

1. those that are used in the petrochemical industry which tend to be covered by standards from TEMA, Tubular Exchanger Manufacturers Association (see [TEMA Standards](#));
2. those that are used in the power industry such as feedwater heaters and power plant condensers.

Regardless of the type of industry the exchanger is to be used in there are a number of common features (see [Condensers](#)).

A shell and tube exchanger consists of a number of tubes mounted inside a cylindrical shell. [Figure 1](#) illustrates a typical unit that may be found in a petrochemical plant. Two fluids can exchange heat, one fluid flows over the outside of the tubes while the second fluid flows through the tubes. The fluids can be single or two phase and can flow in a parallel or a cross/counter flow arrangement.

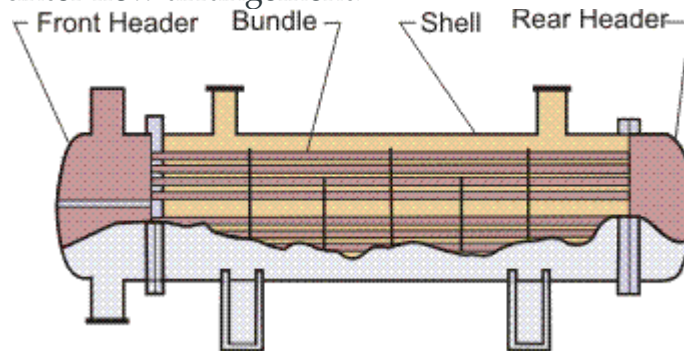


Figure 1. Shell and tube exchanger.

The shell and tube exchanger consists of four major parts:

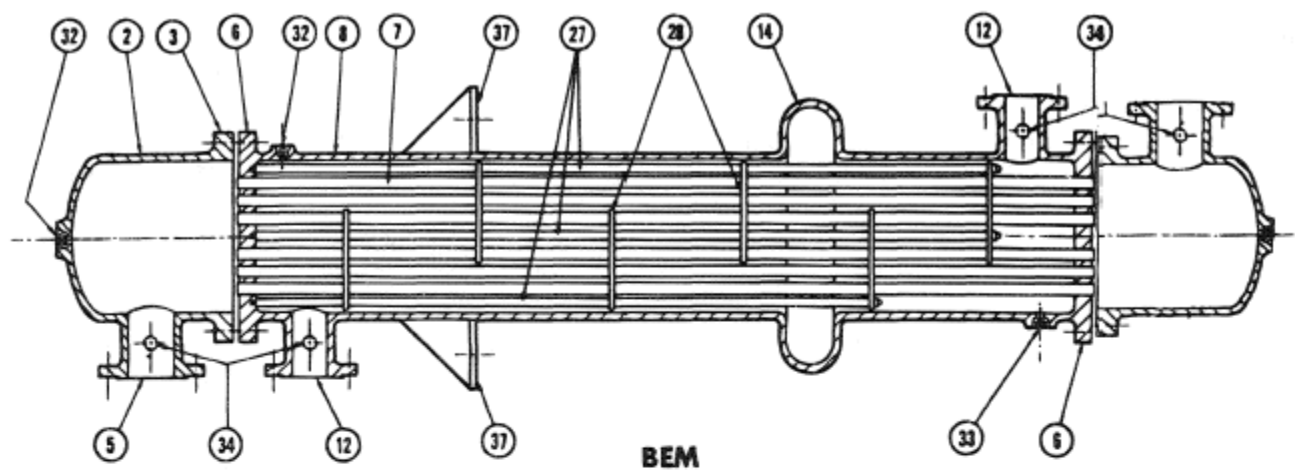
- Front Header—this is where the fluid enters the tubeside of the exchanger. It is sometimes referred to as the Stationary Header.
- Rear Header—this is where the tubeside fluid leaves the exchanger or where it is returned to the front header in exchangers with multiple tubeside passes.
- Tube bundle—this comprises of the tubes, *tube sheets*, *baffles* and tie rods etc. to hold the bundle together.
- Shell—this contains the *tube bundle*.

The remainder of this section concentrates on exchangers that are covered by the TEMA Standard.

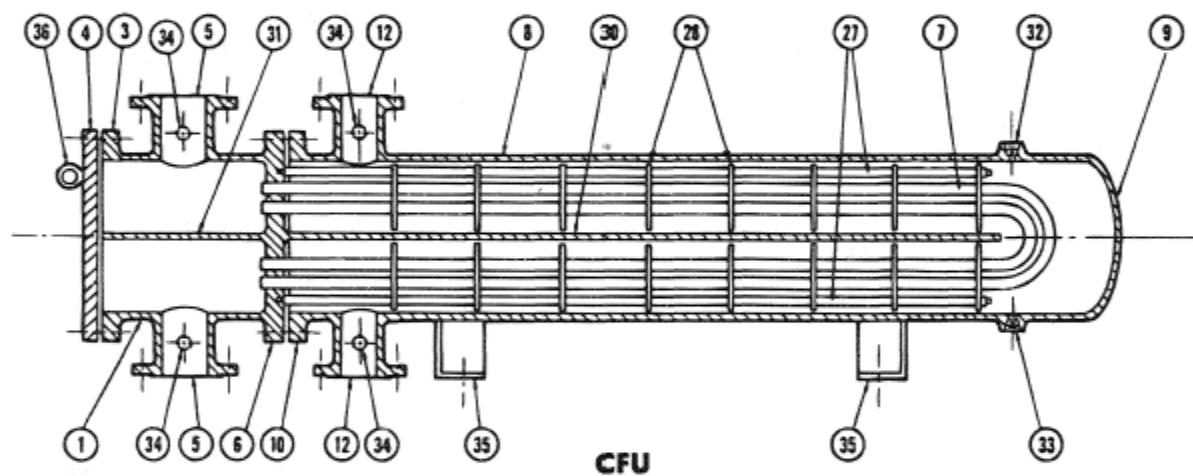
Shell and Tube Exchanger: Geometric Terminology

The main components of a shell and tube exchanger are shown in [Figure 2 a, b](#) and [c](#) and described in [Table 1](#).

a)



b)



c)

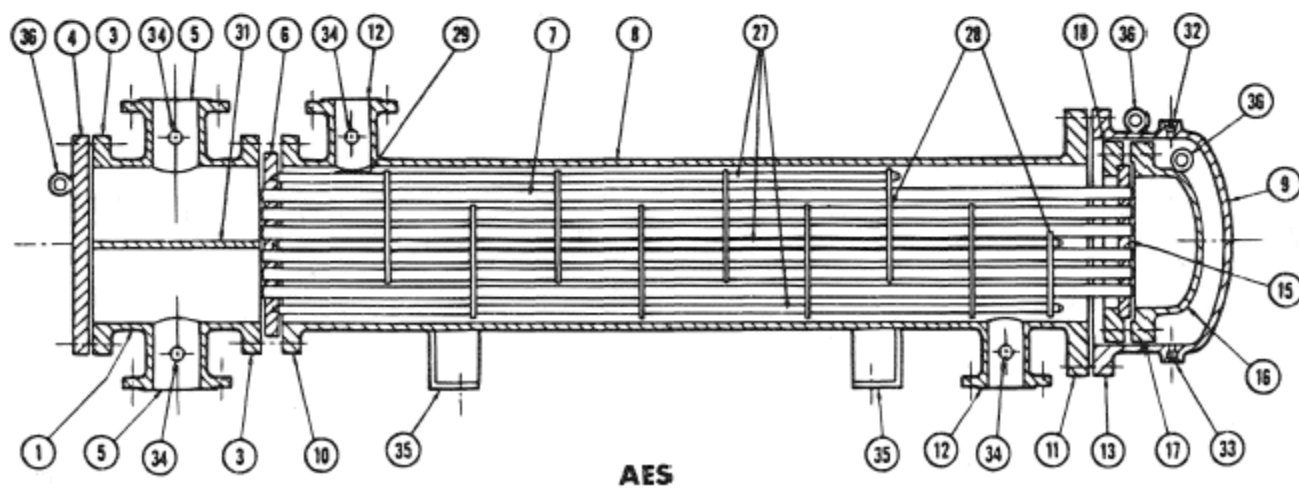


Figure 2. Type BEM, CFU and AES exchangers. © 1988 by Tubular Exchanger Manufacturers Association.

Table 1. Shell and tube geometric terminology

1 Stationary (Front) Head—Channel	20Slip-on Backing Flange
2 Stationary (Front) Head—Bonnet	21Floating Tubesheet Skirt
3 Stationary (Front) Head Flange	22Floating Tubesheet Skirt
4 Channel Cover	23Packing Box Flange
5 Stationary Head Nozzle	24Packing
6 Stationary Tubesheet	25Packing Follower Ring
7 Tubes	26Lantern Ring
8 Shell	27Tie Rods and Spacers
9 Shell Cover	28Transverse Baffles or Support Plates
10Shell Flange—Stationary Head End	29Impingement Baffle or Plate
11Shell Flange—Rear Head End	30Longitudinal Baffle
12Shell Nozzle	31Pass Partition
13Shell Cover Flange	32Vent Connection
14Expansion Joint	33Drain Connection
15Floating Tubesheet	34Instrument Connection
16Floating Head Cover	35Support Saddle
17Floating Head Flange	36Lifting Lug
18Floating Head Backing Device	37Support Bracket
19Split Shear Ring	

Tema Designations

The popularity of shell and tube exchangers has resulted in a standard nomenclature being developed for their designation and use by the Tubular Exchanger Manufacturers Association (TEMA). This nomenclature is defined in terms letters and diagrams. The first letter describes the front header type, the second letter the shell type and the third letter the rear header type. [Figure 2](#) shows examples of a BEM, CFU, and AES exchangers while [Figure 3](#) illustrates the full TEMA nomenclature.

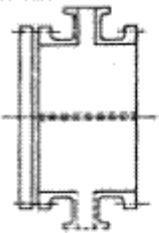
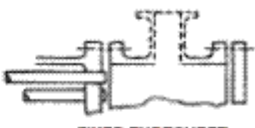
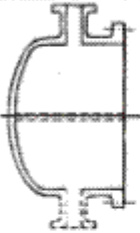
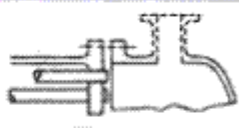
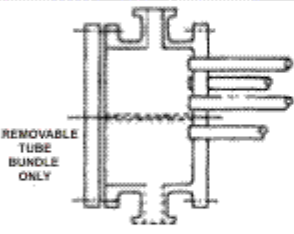
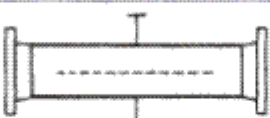
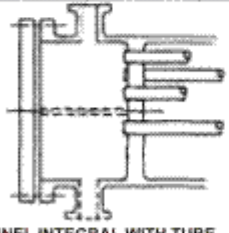
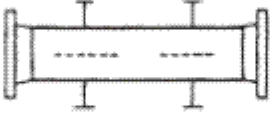
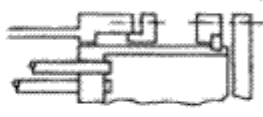
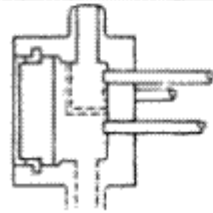
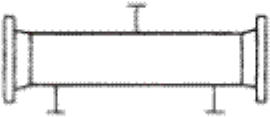
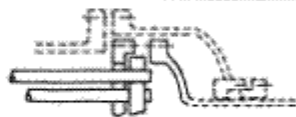
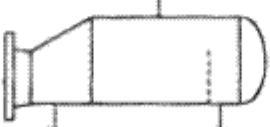
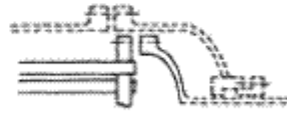
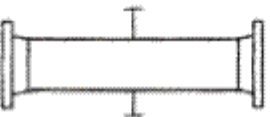
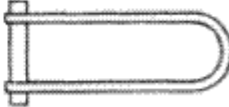
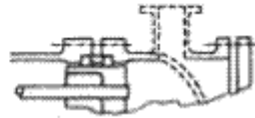
FRONT END STATIONARY HEAD TYPES		SHELL TYPES		READ END HEAD TYPES	
A	 CHANNEL AND REMOVABLE COVER	E	 ONE PASS SHELL	L	 FIXED TUBESHEET LIKE "A" STATIONARY HEAD
B	 BONNET (INTEGRAL COVER)	F	 TWO PASS SHELL WITH LONGITUDINAL BAFFLE	M	 FIXED TUBESHEET LIKE "B" STATIONARY HEAD
C	 REMOVABLE TUBE BUNDLE ONLY CHANNEL INTEGRAL WITH TUBE- SHEET AND REMOVABLE COVER	G	 SPLIT FLOW	N	 FIXED TUBESHEET LIKE "N" STATIONARY HEAD
N	 CHANNEL INTEGRAL WITH TUBE- SHEET AND REMOVABLE COVER	H	 DOUBLE SPLIT FLOW	P	 OUTSIDE PACKED FLOATING HEAD
D	 SPECIAL HIGH PRESSURE CLOSURE	J	 DIVIDED FLOW	S	 FLOATING HEAD WITH BASKING DEVICE
		K	 KETTLE TYPE REBOILER	T	 PULL THROUGH FLOATING HEAD
		X	 CROSS FLOW	U	 U-TUBE BUNDLE
				W	 EXTERNALLY SEALED FLOATING TUBESHEET

Figure 3. TEMA nomenclature. © 1988 by Tubular Exchanger Manufacturers Association.

Many combinations of front header, shell and rear header can be made. The most common combinations for an E-Type Shell are given in [Table 2](#) but other combinations are also used.

Table 2. Shell and tube geometric terminology		
Fixed tubesheet exchangers	U-tube exchangers	Floating head exchangers
AEL	AEU	AES
AEM	CEU	BES
AEN	DEU	
BEL		
BEM		
BEN		

Essentially there are three main combinations

- *Fixed tubesheet exchangers*
- *U-tube exchangers*
- *Floating header exchangers*

Fixed Tubesheet Exchanger (L, M, and N Type Rear Headers)

In a *fixed tubesheet exchanger*, the tubesheet is welded to the shell. This results in a simple and economical construction and the tube bores can be cleaned mechanically or chemically. However, the outside surfaces of the tubes are inaccessible except to chemical cleaning.

If large temperature differences exist between the shell and tube materials, it may be necessary to incorporate an expansion bellows in the shell, to eliminate excessive stresses caused by expansion. Such bellows are often a source of weakness and failure in operation. In circumstances where the consequences of failure are particularly grave U-Tube or Floating Header units are normally used.

This is the cheapest of all removable bundle designs, but is generally slightly more expensive than a fixed tubesheet design at low pressures.

U-Tube Exchangers

In a U-Tube exchanger any of the front header types may be used and the rear header is normally a M-Type. The U-tubes permit unlimited thermal expansion, the tube bundle can be removed for cleaning and small bundle to shell clearances can be achieved. However, since internal cleaning of the tubes by mechanical means is difficult, it is normal only to use this type where the tube side fluids are clean.

Floating Head Exchanger (P, S, T and W Type Rear Headers)

In this type of exchanger the tubesheet at the Rear Header end is not welded to the shell but allowed to move or float. The tubesheet at the Front Header (tube side fluid inlet end) is of a larger diameter than the shell and is sealed in a similar manner to that used in the fixed tubesheet design. The tubesheet at the rear header end of the shell is of slightly smaller diameter than the shell, allowing the bundle to be pulled through the shell. The use of a floating head means that thermal expansion can be allowed for and the tube bundle can be removed for cleaning. There are several rear header types that can be used but the S-Type Rear Head is the most popular. A floating head exchanger is suitable for the rigorous duties associated with high temperatures and pressures but is more expensive (typically of order of 25% for carbon steel construction) than the equivalent fixed tubesheet exchanger.

Considering each header and shell type in turn:

A-Type front header

This type of header is easy to repair and replace. It also gives access to the tubes for cleaning or repair without having to disturb the pipe work. It does however have two seals (one between the tube sheet and header and the other between the header and the end plate). This increases the risk of leakage and the cost of the header over a B-Type Front Header.

B-Type front header

This is the cheapest type of front header. It also is more suitable than the A-Type Front Header for high pressure duties because the header has only one seal. A disadvantage is that to gain access to the tubes requires disturbance to the pipe work in order to remove the header.

C-Type front header

This type of header is for high pressure applications (>100 bar). It does allow access to the tube without disturbing the pipe work but is difficult to repair and replace because the tube bundle is an integral part of the header.

D-Type front header

This is the most expensive type of front header. It is for very high pressures (> 150 bar). It does allow access to the tubes without disturbing the pipe work but is difficult to repair and replace because the tube bundle is an integral part of the header.

N-Type front header

The advantage of this type of header is that the tubes can be accessed without disturbing the pipe work and it is cheaper than an A-Type Front Header. However, they are difficult to maintain and replace as the header and tube sheet are an integral part of the shell.

Y-Type front header

Strictly speaking this is not a TEMA designated type but is generally recognized. It can be used as a front or rear header and is used when the exchanger is to be used in a pipe line. It is cheaper than other types of headers as it reduces piping costs. It is mainly used with single tube pass units although with suitable partitioning any odd number of passes can be allowed.

E-Type shell

This is most commonly used shell type, suitable for most duties and applications. Other shell types only tend to be used for special duties or applications.

F-Type shell

This is generally used when pure countercurrent flow is required in a two tube side pass unit. This is achieved by having two shells side passes—the two passes being separated by a longitudinal baffle. The main problem with this type of unit is thermal and hydraulic leakage across this longitudinal baffle unless special precautions are taken.

G-Type shell

This is used for horizontal thermosyphon reboilers and applications where the shellside pressure drop needs to be kept small. This is achieved by splitting the shellside flow.

H-Type shell

This is used for similar applications to G-Type Shell but tends to be used when larger units are required.

J-Type shell

This tends to be used when the maximum allowable pressure drop is exceeded in an E-Type Shell even when double segmental baffles are used. It is also used when tube

vibration is a problem. The divided flow on the shellside reduces the flow velocities over the tubes and hence reduces the pressure drop and the likelihood of tube vibration. When there are two inlet nozzles and one outlet nozzle this is sometimes referred to as an I-Type Shell.

K-Type shell

This is used only for reboilers to provide a large disengagement space in order to minimize shellside liquid carry over. Alternatively a K-Type Shell may be used as a chiller. In this case the main process is to cool the tube side fluid by boiling a fluid on the shellside.

X-Type shell

This is used if the maximum shellside pressure drop is exceeded by all other shell and baffle type combinations. The main applications are shellside condensers and gas coolers.

L-Type rear header

This type of header is for use with fixed tubesheets only, since the tubesheet is welded to the shell and access to the outside of the tubes is not possible. The main advantages of this type of header are that access can be gained to the inside of the tubes without having to remove any pipework and the bundle to shell clearances are small. The main disadvantage is that a bellows or an expansion roll are required to allow for large thermal expansions and this limits the permitted operating temperature and pressure.

M-Type rear header

This type of header is similar to the L-Type Rear Header but it is slightly cheaper. However, the header has to be removed to gain access to the inside of the tubes. Again, special measures have to be taken to cope with large thermal expansions and this limits the permitted operating temperature and pressure.

N-Type rear header

The advantage of this type of header is that the tubes can be accessed without disturbing the pipe work. However, they are difficult to maintain and replace since the header and tube sheet are an integral part of the shell.

P-Type rear header

This is an outside packed floating rear header. It is, in theory, a low cost floating head design which allows access to the inside of the tubes for cleaning and also allows the bundle to be removed for cleaning. The main problems with this type of header are:

- large bundle to shell clearances required in order to pull the bundle;
- it is limited to low pressure nonhazardous fluids, because it is possible for the shellside fluid to leak via the packing rings;
- only small thermal expansions are permitted.

In practice it is not a low cost design, because the shell has to be rolled to small tolerances for the packing to be effective.

S-Type rear header

This is a floating rear header with backing device. It is the most expensive of the floating head types but does allow the bundle to be removed and unlimited thermal expansion is possible. It also has smaller shell to bundle clearances than the other floating head types. However, it is difficult to dismantle for bundle pulling and the shell diameter and bundle to shell clearances are larger than for fixed head type exchangers.

T-Type rear header

This is a pull through floating head. It is cheaper and easier to remove the bundle than with the S-Type Rear Header, but still allows for unlimited thermal expansion. It does, however, have the largest bundle to shell clearance of all the floating head types and is more expensive than fixed header and U-tube types.

U-tube

This is the cheapest of all removable bundle designs, but is generally slightly more expensive than a fixed tubesheet design at low pressures. However, it permits unlimited thermal expansion, allows the bundle to be removed to clean the outside of the tubes, has the tightest bundle to shell clearances and is the simplest design. A disadvantage of the U-tube design is that it cannot normally have pure counterflow unless an F-Type Shell is used. Also, U-tube designs are limited to even numbers of tube passes.

W-Type rear header

This is a packed floating tubesheet with lantern ring. It is the cheapest of the floating head designs, allows for unlimited thermal expansion and allows the tube bundle to be removed for cleaning. The main problems with this type of head are:

- the large bundle to shell clearances required to pull the bundle and;
- the limitation to low pressure nonhazardous fluids (because it is possible for both the fluids to leak via the packing rings).

It is also possible for the shell and tube side fluids to become mixed if leakage occurs.

Geometric Options

Tube diameter layout and pitch

Tubes may range in diameter from 12.7 mm (0.5 in) to 50.8 mm (2 in), but 19.05 mm (0.75 in) and 25.4 mm (1 in) are the most common sizes. The tubes are laid out in triangular or square patterns in the tube sheets. See [Figure 4](#).

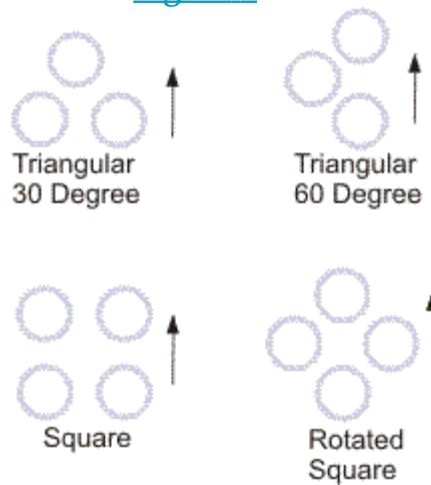


Figure 4. Tube layouts.

The square layouts are required where it is necessary to get at the tube surface for mechanical cleaning. The triangular arrangement allows more tubes in a given space. The tube pitch is the shortest center-to-center distance between tubes. The tube spacing is given by the tube pitch/tube diameter ratio, which is normally 1.25 or 1.33. Since a square layout is used for cleaning purposes, a minimum gap of 6.35 mm (0.25 in) is allowed between tubes.

Baffle types

Baffles are installed on the shell side to give a higher heat-transfer rate due to increased turbulence and to support the tubes thus reducing the chance of damage due to vibration. There are a number of different baffle types, which support the tubes and promote flow across the tubes. [Figure 5](#) shows the following baffle arrangements:

- *Single Segmental* (this is the most common),

- *Double Segmental* (this is used to obtain a lower shellside velocity and pressure drop),
- *Disc and Doughnut*.

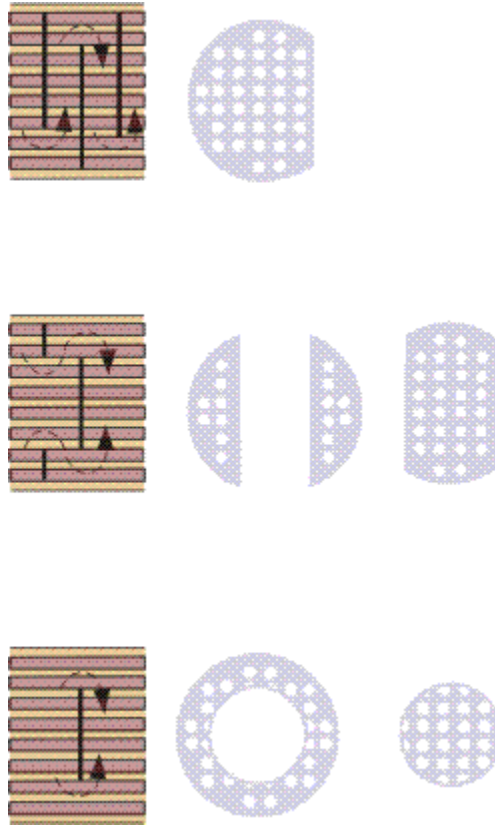


Figure 5. Baffle arrangements.

The center-to-center distance between baffles is called the baffle-pitch and this can be adjusted to vary the crossflow velocity. In practice the baffle pitch is not normally greater than a distance equal to the inside diameter of the shell or closer than a distance equal to one-fifth the diameter or 50.8 mm (2 in) whichever is greater. In order to allow the fluid to flow backwards and forwards across the tubes part of the baffle is cut away. The height of this part is referred to as the baffle-cut and is measured as a percentage of the shell diameter, e.g., 25 per cent baffle-cut. The size of the baffle-cut (or baffle window) needs to be considered along with the baffle pitch. It is normal to size the baffle-cut and baffle pitch to approximately equalize the velocities through the window and in crossflow, respectively.

There are two main types of baffle which give longitudinal flow:

- *Orifice Baffle*,

- *Rod Baffle.*

In these types of baffle the turbulence is generated as the flow crosses the baffle.

Heat Transfer Enhancements Devices

There are three main types.

Special surfaces

These tend to be used to promote nucleate boiling when the temperature driving force is small.

Tube inserts

These are normally *wire wound inserts* or *twisted tapes*. They are normally used with medium to high viscosity fluids to improve heat transfer by increasing turbulence. There is also some evidence that they reduce fouling. In order to use these most effectively the exchanger should be designed for their use. This usually entails increasing the shell diameter, reducing the tube length and the number of tubeside passes in order to allow for the increased pressure loss characteristics of the devices.

Extended surfaces

These are used to increase the heat transfer area when a stream has a low heat transfer coefficient. The most common type is "*low fin tubing*" where typically the fins are 1.5 mm high at 19 fins per inch. (See also [Augmentation of Heat Transfer](#).)

Selection Criteria

In many cases the only way of ensuring optimum selection is to do a full design based on several alternative geometries. In the first instance, however, several important decisions have to be made concerning:

- allocation of fluids to the shellside and tubeside;
- selection of shell type;
- selection of front end header type;
- selection of rear end header type;
- selection of exchanger geometry.

To a large extent these often depend on each other. For instance, the allocation of a dirty fluid to the shellside directly affects the selection of exchanger tube layout.

Fluid allocation

When deciding which side to allocate the hot and cold fluids the following need to be taken into account, in order of priority.

1. Consider any and every safety and reliability aspect and allocate fluids accordingly. Never allocate hazardous fluids such they are contained by anything other than conventional bolted and gasketed—or welded—joints.
2. Ensure that the allocation of fluids complies with established engineering practices, particularly those laid down in customer specifications.
3. Having complied with the above, allocate the fluid likely to cause the most severe mechanical cleaning problems (if any) to the tubeside.
4. If neither of the above are applicable, the allocation of the fluids should be decided only after running two alternative designs and selecting the cheapest (this is time consuming if hand calculations are used but programs such as TASC from the Heat Transfer and Fluid Flow Service (HTFS) make this a trivial task).

Shell selection

E-type shells are the most common. If a single tube pass is used and provided there are more than three baffles, then near counter-current flow is achieved. If two or more tube passes are used, then it is not possible to obtain pure countercurrent flow and the log mean temperature difference must be corrected to allow for combined cocurrent and countercurrent flow using an F-factor.

G-type shells and H shells are normally specified only for horizontal thermosyphon reboilers. J shells and X-type shells should be selected if the allowable DP cannot be accommodated in a reasonable E-type design. For services requiring multiple shells with removable bundles, F-type shells can offer significant savings and should always be considered provided they are not prohibited by customer specifications

Front header selection

The A-type front header is the standard for dirty tubeside fluids and the B-type is the standard for clean tubeside fluids. The A-type is also preferred by many operators regardless of the cleanliness of the tubeside fluid in case access to the tubes is required. Do not use other types unless the following considerations apply.

A C-type head with removable shell should be considered for hazardous tubeside fluids, heavy bundles or services requiring frequent shellside cleaning. The N-type head is used when hazardous fluids are on the tubeside. A D-type head or a B-type head welded to the tubesheet is used for high pressure applications. Y-type heads are only normally used for single tube-pass exchangers when they are installed in line with a pipeline.

Rear header selection

For normal service a Fixed Header (L, M, N-types) can be used provided that there is no overstressing due to differential expansion and the shellside will not require mechanical cleaning. If thermal expansion is likely a fixed header with a bellows can be used provided that the shellside fluid is not hazardous, the shellside pressure does not exceed 35 bar (500 psia) and the shellside will not require mechanical cleaning.

A U-tube unit can be used to overcome thermal expansion problems and allow the bundle to be removed for cleaning. However, countercurrent flow can only be achieved by using an F-type shell and mechanical cleaning of the tubeside can be difficult.

An S-type floating head should be used when thermal expansion needs to be allowed for and access to both sides of the exchanger is required from cleaning. Other rear head types would not normally be considered except for the special cases.

Selection of Exchanger Geometry

Tube outside diameter

For the process industry, 19.05 mm (3/4") tends to be the most common.

Tube wall thickness

Reference must be made to a recognized pressure vessel code to decide this.

Tube length

For a given surface area, the longer the tube length the cheaper the exchanger, although a long thin exchanger may not be feasible.

Tube layout

45 or 90 degree layouts are chosen if mechanical cleaning is required, otherwise a 30 degree layout is often selected, because it provides a higher heat transfer and hence smaller exchanger.

Tube pitch

The smallest allowable pitch of 1.25 times the tube outside diameter is normally used unless there is a requirement to use a larger pitch due to mechanical cleaning or tube end welding.

Number of tube passes

This is usually one or an even number (not normally greater than 16). Increasing the number of passes increases the heat transfer coefficient but care must be taken to ensure that the tube side ρv^2 is not greater than about 10,000 kg/m·s².

Shell diameter

Standard pipe is normally used for shell diameters up to 610 mm (24"). Above this the shell is made from rolled plate. Typically shell diameters range from 152 mm to 3000 mm (6" to 120").

Baffle type

Single segmental baffles are used by default but other types are considered if pressure drop constraints or vibration is a problem.

Baffle spacing

This is decided after trying to balance the desire for increased crossflow velocity and tube support (smaller baffle pitch) and pressure drop constraints (larger baffle pitch). TEMA provides guidance on the maximum and minimum baffle pitch.

Baffle cut

This depends on the baffle type but is typically 45% for single segmental baffles and 25% for double segmental baffles.

Nozzles and impingement

For shellside nozzles the ρv^2 should not be greater than about 9000 in kg/m·s². For tubeside nozzles the maximum ρv^2 should not exceed 2230 kg/m·s² for noncorrosive, nonabrasive single phase fluids and 740 kg/m·s² for other fluids. Impingement protection is always required for gases which are corrosive or abrasive, saturated vapors and two phases mixtures. Shell or bundle entrance or exit areas should be designed such that a ρv^2 of 5950 kg/m·s² is not exceeded.

Materials of Construction

In general, shell and tube exchangers are made of metal, but for specialist applications (e.g., involving strong acids or pharmaceuticals), other materials such as graphite, plastic and glass may be used.

Thermal Design

The thermal design of a shell and tube exchanger is an iterative process which is normally carried out using computer programs from organizations such as the Heat transfer and Fluid Flow Service (HTFS) or Heat Transfer Research Incorporated (HTRI). However, it is important that the engineer understands the logic behind the calculation. In order to calculate the heat transfer coefficients and pressure drops, initial decisions must be made on the sides the fluids are allocated, the front and rear header type, shell type, baffle type, tube diameter and tube layout. The tube length, shell diameter, baffle pitch and number of tube passes are also selected and these are normally the main items that are altered during each iteration in order to maximize the overall heat transfer within specified allowable pressure drops.

The main steps in the calculation are given below together with calculation methods in the open literature:

1. Calculate the shellside flow distribution [Use *Bell-Delaware Method*, see Hewitt, Shires, and Bott (1994)].
2. Calculate the shellside heat transfer coefficient (Use Bell- Delaware Method)
3. Calculate tubeside heat transfer coefficient (see, for example, [Tubes: Single Phase Heat Transfer In](#)).
4. Calculate tubeside pressure drop (see, for example, [Pressure Drop, Single Phase](#)).
5. Calculate wall resistance and overall heat transfer coefficient (see [Overall Heat Transfer Coefficient](#) and [Fouling](#)).
6. Calculate mean temperature difference (see [Mean Temperature Difference](#)).
7. Calculate area required.
8. Compare area required with area of assumed geometry and allowed tubeside and shellside pressure drop with calculated values.
9. Adjust assumed geometry and repeat calculations until Area required is achieved within the allowable pressure drops.

Books by E. A. D. Saunders [Saunders (1988)] and G. F. Hewitt, G. L. Shires, and T. R. Bott [Hewitt et al. (1994)] provides a good overview of tubular thermal design methods and example calculations.

Mechanical Design

The mechanical design of a shell and tube heat exchanger provides information on items such as shell thickness, flange thickness, etc. These are calculated using a pressure vessel design code such as the Boiler and Pressure Vessel code from ASME (American Society of Mechanical Engineers) and the British Master Pressure Vessel Standard, BS 5500. ASME is the most commonly used code for heat exchangers and is in 11 sections. Section VIII (Confined Pressure Vessels) of the code is the most applicable to heat exchangers but Sections II—Materials and Section V—Non Destructive Testing are also relevant.

Both ASME and BS5500 are widely used and accepted throughout the world but some countries insist that their own national codes are used. In order to try and simplify this the International Standards Organization is now attempting to develop a new internationally recognized code but it is likely to be a some time before this is accepted.

References

1. TEMA Seventh Edition. (1988) Tubular Exchanger Manufacturers Association.
2. Saunders, E. A. D. (1988) *Heat Exchangers—Selection, Design and Construction*, Longman Scientific and Technical.
3. [Hewitt](#), G. F, Shires, G. L., and Bott, T. R. (1994) *Process Heat Transfer*, CRC Press.
4. Boiler and Pressure Vessel code, ASME (American Society of Mechanical Engineers).
5. British Master Pressure Vessel Standard, BS 5500