Fluid allocations in shell and tube heat exchangers

Fluid allocation in shell and tube heat exchangers is a key decision during the design of the exchanger to ensure the achievement of the required thermal duty with optimized cost and satisfactory in-service reliability. The selection of the correct side for each fluid depends on many interacting factors, some related to the thermal design and some others related to the mechanical design and future considerations of inspection and integrity monitoring of the exchanger.

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The best choice of routing can only be decided after designing both options in many cases. In some cases, the selected side for each fluid is a tradeoff decision as there might be no one single selection which satisfies all the required factors, and some may conflict with others. Hence, understanding the effect of each parameter and the main features of each heat exchanger type is very important to help in selecting the right optimized design.

In addition, each of the exchanger types (fixed tubesheet, floating head tubesheet, or U tube heat exchanger) has its own characteristics, which will be preferred for specific fluid applications over other types.

Main factors affecting fluid allocation:

Allowable pressure drop: Flow areas in the shell side is higher than that of the tube side and flow resistance and associated pressure drop will be lower. Fluids, of which pressure drop should be low to satisfy the limiting operating conditions in the plant, should be allocated in the shell side.

Fluid operating pressure and temperature: It is preferred to have the higher pressure fluid in the tube side of the exchanger rather than the shell side, as the thickness of the pressure part is proportional with its diameter. An example for that is the equation of the thickness required for the cylindrical part under internal pressure ($t=PR/SE-0.6P$) [6] where 't' is the required thickness and 'R' is internal radius and 'S' is the material allowable stress. A thick shell will impact the cost, foundation design, and might impact the fabricability of the shell (welding, forming and inspection requirements).

In some cases, routing the higher-pressure fluid through the shell may produce a cheaper unit, particularly if it reduces the exchanger diameter and it is made of carbon steel.[1]

The impact of temperature is sometimes similar as, at high temperature, the material strength is reduced and thus results in the allowable stress value ('S' in the equation). That will result in higher calculated thickness which is preferred in the tube side.

While allocating the higher pressure fluid in the tube side it is worth considering the 10/13 rule during the determination of the shell side design pressure, if possible. Sometimes a minor increase in shell side design pressure can achieve the 10/13 rule explained in the box text.

Fluid viscosity: For highly viscous fluids, turbulent flow can be obtained easier at the shell side due to the effect of baffles in changes of flow direction. It is preferred to pass higher viscous fluids in shell side.

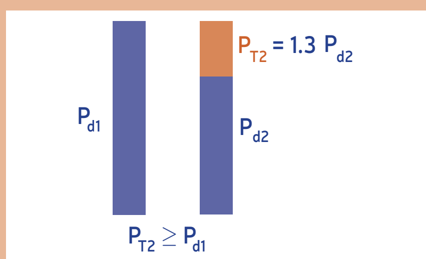
Viscous fluids also tend to have a higher pressure drop which supports routing them to the shell side to minimize the pressure drop.

Fluid heat transfer rate: Fluid with low heat transfer coefficients is preferred to be located in the shell side as it can be more flexible to enhance the heat transfer by changing the flow patterns using the baffles as the heat transfer is much higher for turbulence flow. If that fluid is located in tube side, then a higher number of tube passes can be used for the velocity and flow turbulence.

Fluid phases (one phase or two phases): Fluids which undergo phase changes should be located in the shell side. Here, a large flow area can be used to accommodate vapor flow without increasing the pressure drop. Whereas the flow which is condensed during the heat transfer is usually located in the tube side.

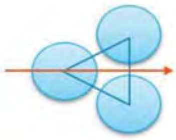
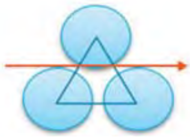
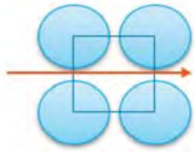
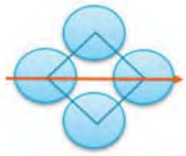
10/13 Rule

Loss of containment of the low-pressure side of shell and tube heat exchangers to atmosphere is unlikely to result from a tube rupture where the pressure in the low-pressure side during the tube rupture does not exceed the corrected hydrotest pressure. [5] In such cases, the exchanger can be considered protected from an overpressure scenario by design and there will be no need to use overpressure protection device (PSV or Rupture disk).



10/13 Rule for overpressure protection.

Table 1.

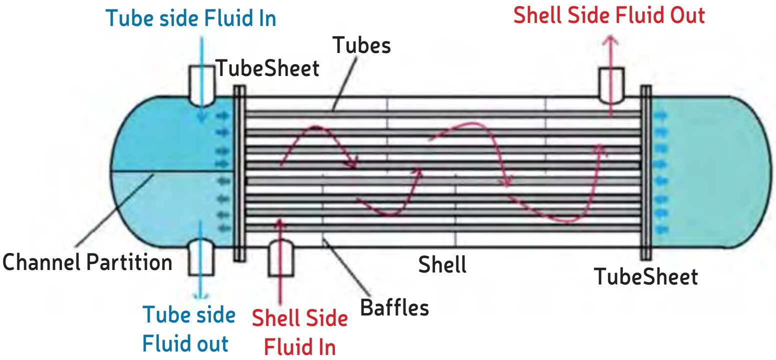
	Triangular		Square	
	30° 	60° Rotated 	90° 	45° Rotated 
Applicable shell side fluid	Low fouling tendency due to the difficulty of mechanical cleaning		No limitation	
Pressure drop(Shell side)	Larger than square		Smaller than triangular	
	Larger than rotated triangular	Smaller than triangular	Smaller than rotated square	Larger than square
Heat Transfer coefficient (shell side)	Higher than triangular		Lower than triangular	

Dirty Fluids: Dirty fluids and fluids that contain suspended solids are better to be located in the tube side as it is much easier to clean than the shell side.
In case dirty fluids need to be located in the shell side due to other considerations, it is preferred to use square tube pitch instead of a triangular pitch (despite lower heat transfer) in order to facilitate cleaning the tube bundle from the shell side. Table 1 summarizes the main features of each of each tube pitch.
Fluid corrosivity: The effect of corrosion on selecting the ideal exchanger side for each fluid is difficult to conclude however, as a general rule, it is usual to route the more expensive material in the tube side. In some cases, if the fluid is not at high pressure and the switch reduces the shell diameter, it may provide a cheaper solution. [1]
When the shell side fluid is prone to cracking, fixed tubesheet exchangers should be avoided and all internal welds should be accessible for inspection. In addition, if a fluid has tendency to cause crevice corrosion it is better to be routed in the tube side to avoid crevice corrosion between tube and tubesheet at the backside of the tubesheet.
Cooling water: Low velocities can promote increased corrosion. There must be sufficient velocity to maintain any particulate in suspension as it travels through the heat exchanger [7]. Velocities below about 3 fps (1 m/s) are likely to result in fouling, sedimentation, and increased corrosion in fresh and brackish water systems. Accelerated corrosion can also result from dead spots or stagnant areas if cooling water used on the shell side of heat exchangers rather than the preferred tube side. Velocity limits depend on the tube material and water quality.
With very few exceptions, cooling water should be on the tube side to minimize stagnant areas. [2]
On the other hand, high water velocity can increase the corrosion by erosion corrosion mechanism and also by allowing more oxygen to be carried to cathodic sites increasing the cathodic reaction rate. Hence, both very high and very low water velocities should be avoided. [3]

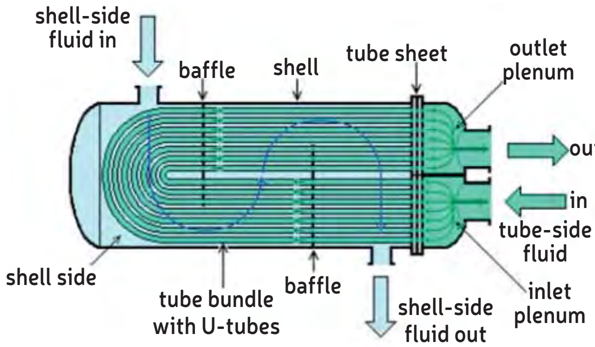
Bundle with cooling water in shell side.

Main features of shell and tube for selection of fluid allocation

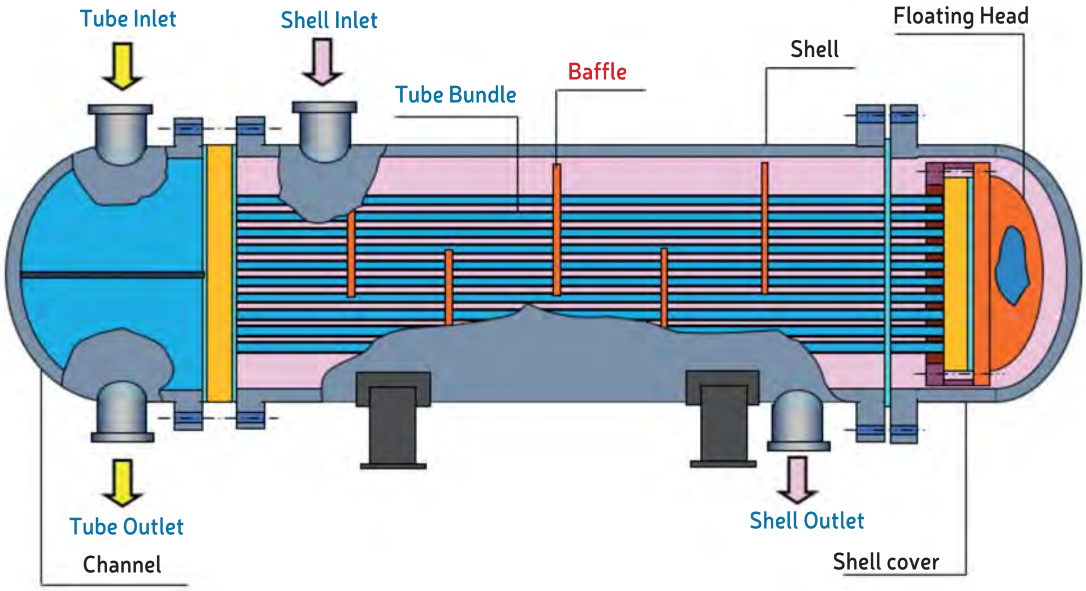
Fixed tubesheet heat exchanger: A fixed tubesheet heat exchanger has straight tubes that are secured at both ends to tubesheets welded to the shell barrel.



Fixed tubesheet heat exchanger.



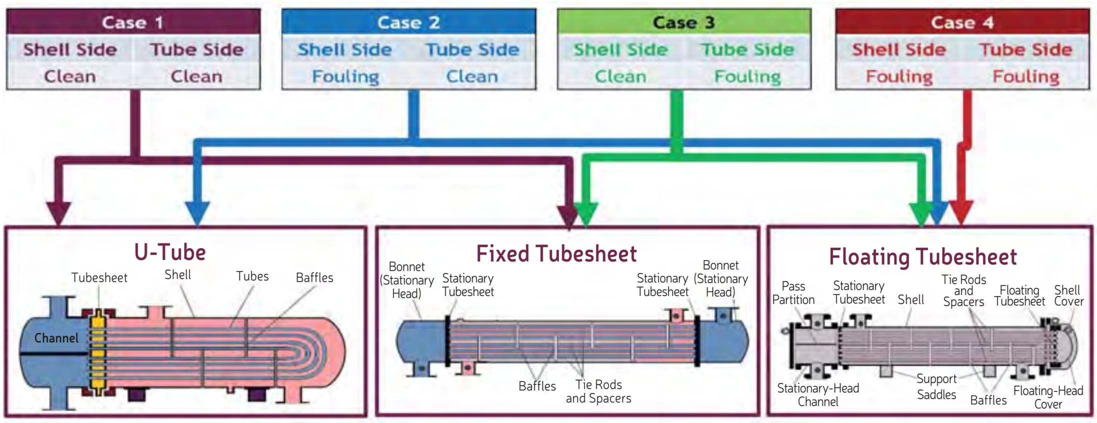
U tube heat exchanger.



Floating heat exchanger.

The principal advantage of the fixed tubesheet construction is its low cost (as expansion joint is not required) because of its simple construction.
The outsides of the tubes cannot be cleaned mechanically (but can be chemically cleaned). Thus, its application is limited to clean services on the shell side. Shell internal and tube bundle external surface cannot be inspected.
U tube heat exchanger: The tubes of a U tube heat exchanger are bent in the shape of a U and there is only one tubesheet.
In a U tube heat exchanger one end is free and the bundle can expand or contract in response to stress differentials. In addition, the outsides of the tubes can be cleaned, as the tube bundle can be removed.
The main disadvantage of the U tube construction is that the insides of the tubes cannot be cleaned effectively, since the U bends would require flexible end drill shafts for cleaning. Thus, U tube heat exchangers should not be used for services with a dirty fluid inside the tubes. Another limitation is the inspection of the U bend area; most of the commercially available inspection techniques could not pass through the bend areas unless using smaller probe Fill Factor (FF) and hence less accuracy in the inspection results. A large fill factor (e.g. 85%) is desirable for optimal NDE (Non Destructive Examination) performance. [4]
Compared to fixed tubesheet the cost will be in the same range; although it will save the cost of the second tubesheet, it will also have the added cost for the bending of the tubes and in many cases the stress relief heat treatment required for the U bend area. In addition, a relative larger shell diameter due to the minimum U bend radius limitation increases cost as well.
Floating head heat exchanger: A floating head heat exchanger is the most versatile type of shell and tube heat exchanger, and also the highest in cost.
In this design, one tubesheet is fixed relative to the shell, and the other is free to float within the shell. This permits free expansion of the tube bundle, as well as cleaning of both the insides and outsides of the tubes. Floating head shell and tube heat exchangers can be used for services where both the shell side and the tube side fluids are dirty, making this the standard construction type used in dirty services, such as in petroleum refineries.

References available upon request from the Editor: e.pritchard@kci-world.com



Guidance for selecting TEMA type based on whether fluid is clean or dirty.

About the author
Baher Elsheikh is a Mechanical Engineer at SABIC. He has seventeen years of experience in the engineering, reliability, construction, commissioning and inspection management of pressure equipment, piping systems, fired heaters, and power boilers.