KLM Technology Group

Practical Engineering Guidelines
for Processing Plant Solutions

KLM Technology Group

Solutions Standards Software

www.klmtechgroup.com

Rev: 04

Rev 01 January 2008
Rev 02 November 2010
Rev 03 October 2014
Rev 04 January 2015

KLM Technology Group
#03-12 Block Aronia,
Jalan Sri Perkasa 2
Taman Tampoi Utama
81200 Johor Bahru.
Malaysia

Kolmetz Handbook
Of Process Equipment Design

HEAT EXCHANGER SELECTION AND SIZING

(ENGINEERING DESIGN GUIDELINE)

Co Author:
Rev 01 A L Ling
Rev 02 Viska Mulyandasari
Rev 03 Yurika Mandasari
Rev 04 Mela Widiawati

Author / Editor:
Karl Kolmetz

TABLE OF CONTENT

INTRODUCTION

THEORY

APPLICATION

LIST OF TABLE

LIST OF FIGURE

INTRODUCTION

Scope

This design guideline covers the selection and sizing methods for heat exchangers which are commonly used in typical industrial processes. It helps engineers, operations personnel and maintenance personnel to understand the basic designs of different types of heat exchangers, and increases their knowledge in selection and sizing. A heat exchanger is a device for heat transfer from one medium to another.

The basic concept of a heat exchanger is based on the premise that the loss of heat on the high temperature side is exactly the same as the heat gained in the low temperature side after the heat and mass flows through the heat exchanger. Heat exchanger 'simply' exchanges the heat between those two sides; as a result, it is decreasing the temperature of higher temperature side and increasing the temperature of lower temperature side. But designing heat exchanger might be a challenge; it needs iteration for manual calculation. Hence, a guideline to properly select and sizing is needed.

Many factors have to be considered in heat exchanger selection. Generally, suitability of types of heat exchanger to be used in processing industrials is selected based on Industry Standards. The standards divides heat exchanger into classes based on their application. Comparison of each class in the standard is summarised in this guideline. Besides, various type of heat exchanger with their best suitable application and limitation are also listed in this guideline.

Selection might be done by referred to some valid standards or guideline, but understanding the basic concept and theory behind heat exchanger is also important. Furthermore, basic theories about heat transfer are also extremely needed to do heat exchanger sizing. Hence, some theories are included in this guideline.

Selection and sizing are related each other; changing in heat exchanger component, such as tube pattern and baffle, would affect the calculation. Some required data is commonly pictured in a graph or listed in a table and they are attached in this guideline as well. To do manual calculation, it is mentioned before, iteration is needed. This guideline gives some approximation values as a 'boundary' for iteration. The step by step sizing method is also explained in this guideline to simplify the calculation.

In the application section, multiple cases examples are included to guide the reader by using the step-by-step method to do heat exchanger sizing. A calculation spreadsheet is also included as well to aid user more understand the calculation. This spreadsheet is also helpful to make the calculation even easier.

General Considerations

Why Use Heat Exchangers

1. To cool process streams
   a. Gasoline product going to storage is cooled to reduce loses because of its vapor pressure.
   b. General unit intercoolers remove the heat of reaction between reactors
   c. Absorber intercoolers on gas concentration units remove the heat of absorption and thereby increase the efficiency of the absorber
   d. Fractionator condensers condense the overhead, part of which may be the product and the other part of which may be reflux that is returned to the column to help effect a separation
2. To heat process streams
   a. Fractionator reboilers are used to add heat to fractionation column that effects a separation.
   b. Reactor charge heaters are used to heat the feed up to the reaction temperature.
3. To exchange heat between hot and cold process streams
   a. Feed exchangers that is used to heat the reactor charge by exchanging heat with the reactor effluent

b. Fractionator feed-bottoms exchanger that is used to heat the feed by exchanging heat with the bottoms

Heat Exchanger Type

Heat transfer equipment is usually specified both by type of construction and by service.

A heat exchanger is a specialized device that assists in the transfer of heat from one fluid to the other. In some cases, a solid wall may separate the fluids and prevent them from mixing. In other designs, the fluids may be in direct contact with each other. In the most efficient heat exchangers, the surface area of the wall between the fluids is maximized while simultaneously minimizing the fluid flow resistance. Fins or corrugations are sometimes used with the wall in order to increase the surface area and to induce turbulence.

In heat exchanger design, there are three types of flow arrangements: counter-flow, parallel-flow, and cross-flow. In the counter-flow heat exchanger, both fluids entered the exchanger from opposite sides. In the parallel-flow heat exchanger, the fluids come in from the same end and move parallel to each other as they flow to the other side. The cross-flow heat exchanger moves the fluids in a perpendicular fashion. Compare to other flow arrangements counter flow is the most efficient design because it transfers the greatest amount of heat.

There are two major different designs of heat exchangers: shell and tube, and plate heat exchanger. The most typical type of heat exchanger is the shell and tube design. This heat exchanger can be design with bare tube or finned tubes. One of the fluids runs through the tubes while the other fluid runs over them, causing it to be heated or cooled. In the plate heat exchanger, the fluid flows through baffles. This causes the fluids to be separated by plates with a large surface area. This type of heat exchanger is typically more efficient than the shell and tube design.

(A) Shell & Tube Exchanger

A shell and tube heat exchanger is a class of heat exchanger designs. It is the most common type of heat exchanger in oil refineries and other large chemical processes, and is suited for higher-pressure applications. It consists of a tube bundle enclosed in a cylindrical casing called a shell. One fluid runs through the tubes, and another fluid flows over the tubes (through the shell) to transfer heat between the two fluids.

Two fluids, of different starting temperatures, flow through the heat exchanger. One flows through the tubes (the tube side) and the other flows outside the tubes but inside the shell (the shell side). Heat is transferred from one fluid to the other through the tube walls, either from tube side to shell side or vice versa. The fluids can be either liquids or gases on either the shell or the tube side. In order to transfer heat efficiently, a large heat transfer area should be used, so there are many tubes. In this way, waste heat can be put to use. This is a great way to conserve energy.

Typically, the ends of each tube are connected to plenums through holes in tube sheets. The tubes may be straight or bent in the shape of a U, called U-tubes. Most shell-and-tube heat exchangers are either 1, 2, or 4 pass designs on the tube side. This refers to the number of times the fluid in the tubes passes through the fluid in the shell. In a single pass heat exchanger, the fluid goes in one end of each tube and out the other.

There are two basic types of shell-and-tube exchangers. The first is the fixed tube sheet unit, in which both tube sheets are fastened to the shell and the tube bundle is not removable. The second type of shell-and-tube unit has one restrained tube sheet, called the stationary tube sheet, located at the channel end. Differential expansion problems are avoided by use of a freely riding floating tube sheet at the other end or the use of U tubes. This design may be used for single or multiple pass exchangers. The tube bundle is removable from the channel end, for maintenance and mechanical cleaning.

There are often baffles directing flow through the shell side so the fluid does not take a short cut through the shell side leaving ineffective low flow volumes.

Counter current heat exchangers are most efficient because they allow the highest log mean temperature difference between the hot and cold streams. Many companies however do not use single pass heat exchangers because they can break easily in addition to being more expensive to build. Often multiple heat exchangers can be used to simulate the counter current flow of a single large exchanger.

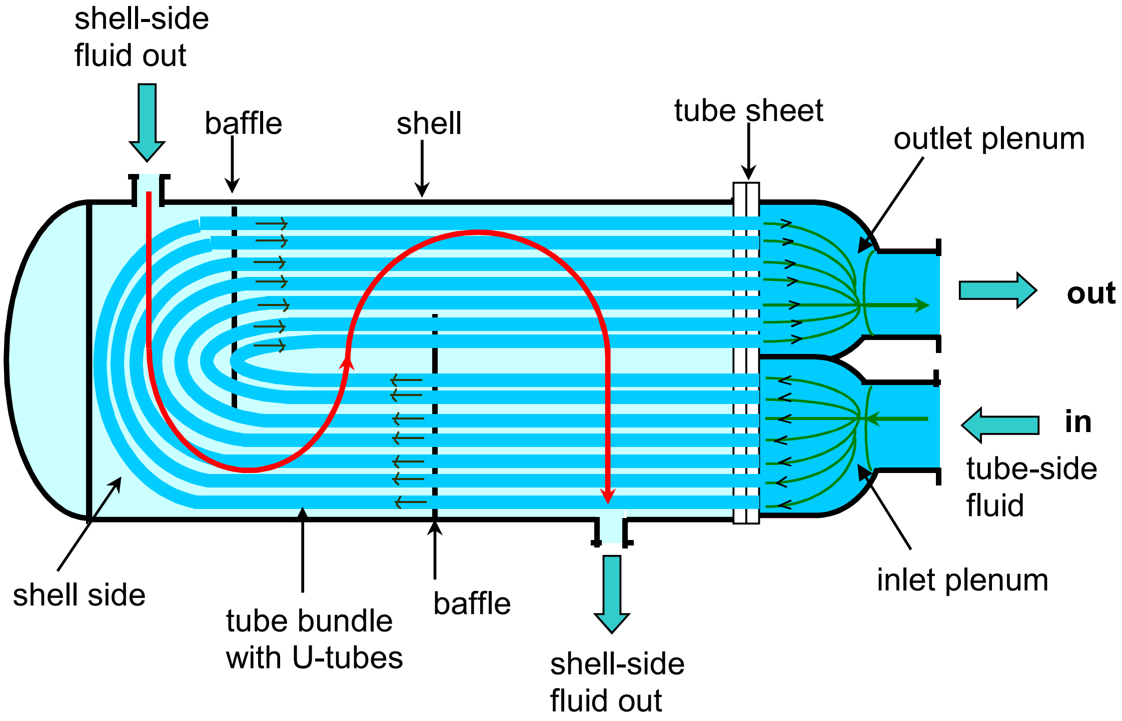


Figure 1: U-tube Heat Exchanger

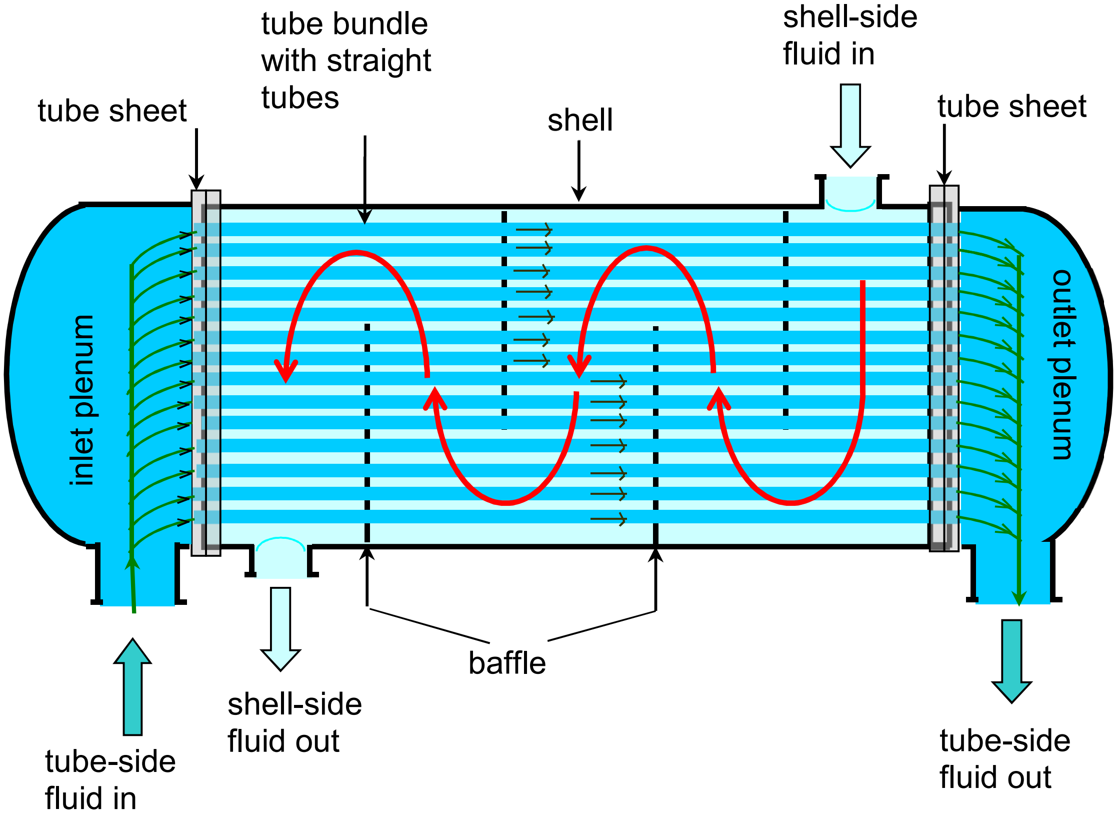


Figure 2: Straight Tube Heat Exchanger (One Pass Tube-Side: Counter current Flow)

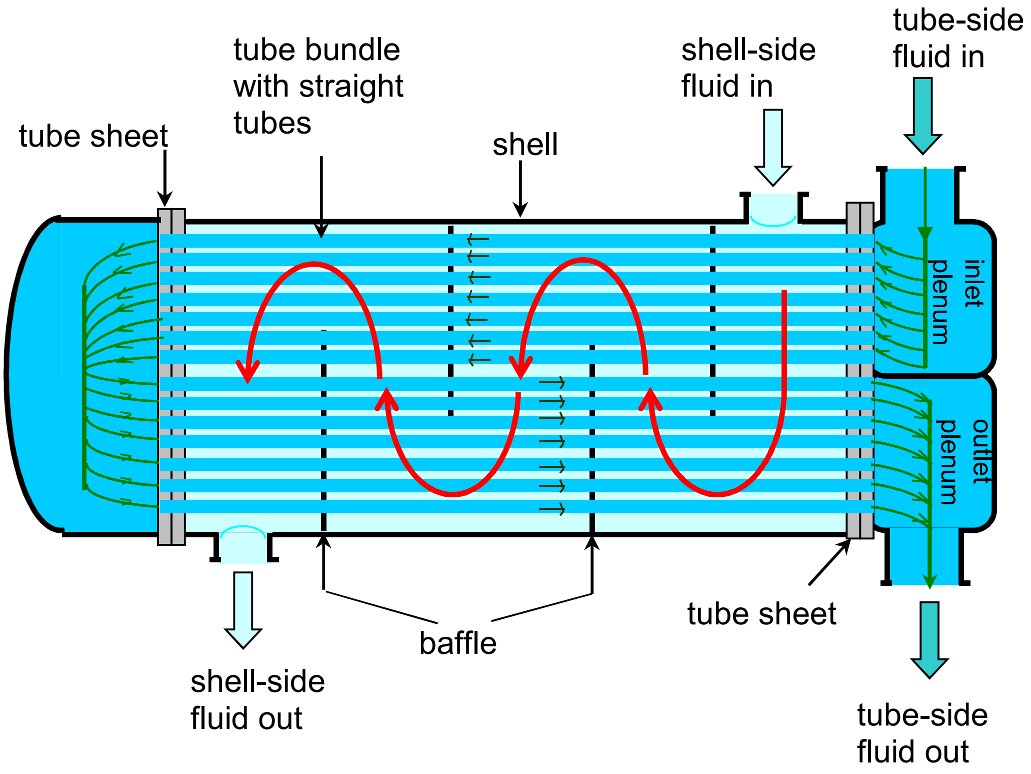


Figure 3: Straight Tube Heat Exchanger (Two Pass Tube Side)

Figure 4: Type 500 Shell & Tube Heat Exchangers

(B) Plate Heat Exchangers

Plate and frame heat exchanger for general refinery service can be referred as gasketed plate heat exchangers. The plate heat exchanger consists of a frame, which consists of a head, follower, column, carrying bar, guiding bar, and a number of clamping bolts. In between head and follower a varying number of pressed plates are clamped together. Each plate is supplied with a gasket, so that the plates form a closed system of parallel flow channels, through which the media flow alternatively at every second interval.

The gaskets are glued on the plates, securing tightness between media and the atmosphere. Between the different media there are double gaskets, which have intermediate drain areas, meaning that mixing of the two media is impossible. Every second plate in the stack has to

These design guideline are believed to be as accurate as possible, but are very general and not for specific design cases. They were designed for engineers to do preliminary designs and process specification sheets. The final design must always be guaranteed for the service selected by the manufacturing vendor, but these guidelines will greatly reduce the amount of up front engineering hours that are required to develop the final design. The guidelines are a training tool for young engineers or a resource for engineers with experience.

This document is entrusted to the recipient personally, but the copyright remains with us. It must not be copied, reproduced or in any way communicated or made accessible to third parties without our written consent.

turn 180°, so that the plates form a closed system of parallel flow channels, through which the media flow alternatively at every second interval.

The advantage of the gasketed plate heat exchanger:

(i) High thermal efficiency due to high film efficiency of heat transfer for both fluids, no bypassing and leakage streams, and counter-current operation.

(ii) Plate design is feasible with size, chevrons angles and pass arrangements.

(iii) Easy maintenance that the plate can be easily disassembled for cleaning.

(iv) The plates of the unit can be rearranged, added or removed from the plate rack to suit for difference of service condition.

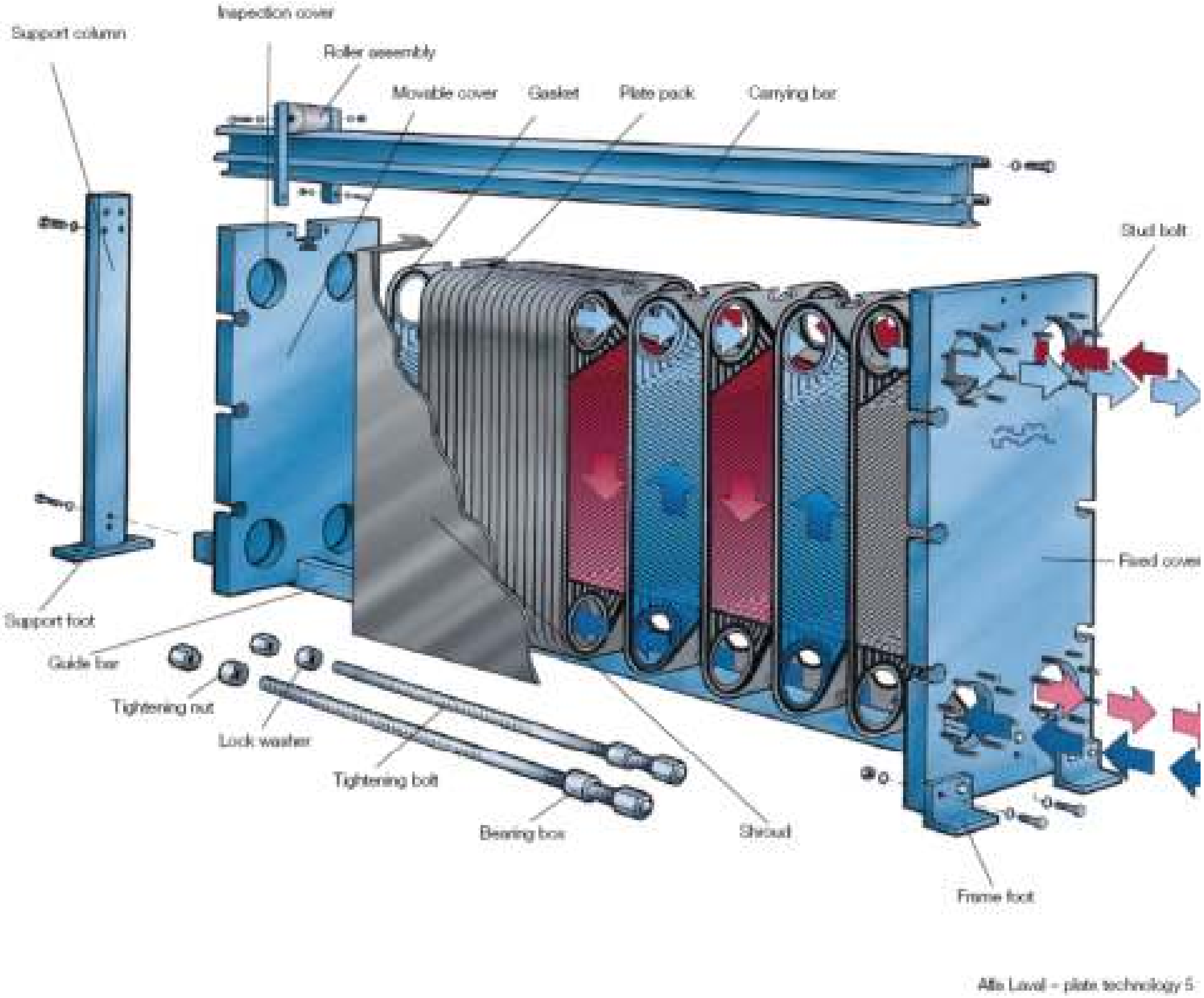
(v) Have very wide range of total surface area up to 15,000 ft^2.

(vi)Low fouling is encountered due to high turbulence create by plate and the fluid low residence in plate.

The disadvantage,

(i) Have limitations in service temperature and pressure. Maximum service temperature is 450^{o}F and pressure is 335 psig.

(ii) The gaskets impose restrictions on the nature of the fluids which can be handled.



Alfa Laval – plate technology 5

Figure 5: Plate Heat Exchanger

Figure 6: Welded Heat Exchanger (Plate Type)

Design Consideration

Shell and tube exchanger: general design considerations

- Fluid allocation : shell or tubes
  Where no phase change occurs, the following factors determine the allocation of the fluid streams to the shell or tubes.

  **corrosion.* The more corrosive fluid should be allocated to the tube side. This will reduce the cost of expensive alloy or clad components.

  **Fouling*. The fluid that has the greatest tendency to foul the heat-transfer surfaces should be placed in the tubes. This gives better control over the design fluid velocity, and the higher allowable velocity in the tubes will reduce fouling. Also, the tubes will be easier to clean.

  **Fluid temperatures*. If the temperature are high enough to require the use of special alloys, placing the higher temperature fluid in the tubes will reduce the shell surface temperatures, and hence the need for lagging to reduce heat loss or for safety reasons.

  **Operating pressures*. The higher pressure stream should be allocated to the tube side. High-pressure tube will be cheaper than a high-pressure shell. The required tube thickness is less for high internal pressure than high external pressure and an expensive high-pressure shell may be avoided.

  **Pressure drop*. For the same pressure drop, higher heat-transfer coefficients will be obtained on the tube side than the shell side, and fluid with the lowest allowable pressure drop should be allocated to the tube side.

  **Viscosity*. Generally, a higher heat-transfer coefficient will be obtained by allocating the more viscous material to the shell side, providing the flow is turbulent. The critical Reynolds number for turbulent flow in the shell is in the region of 200. If turbulent flow cannot be achieved in the shell, it is better to place the fluid in the tubes, as the tube-side heat transfer coefficient can be predicted with more certainly.

Stream flow rates. Allocating the fluids with the lowest flow rate to the shell side will normally give the most economical design.

- Shell and tube fluid velocities

  *liquids – tube side, process fluids; 1 to 2 m/s, maximum 4 m/s if required to reduce fouling; water: 1.5 to 2.5 m/s.

  Shell side: 0.3 to 1 m/s.

  *vapors – for vapors, the velocity used will depend on the operating pressure and fluid density; the lower values in the ranges given below will apply to high molecular weight materials.

➢ Vacuum	50 to 70 m/s
➢ Atmospheric pressure	10 to 30 m/s
➢ High pressure	5 to 10 m/s

- Stream temperatures

- Pressure drop

  *Liquids

Viscosity	Allowable Pressure Drop
<1mN s/m2	35 kN/m2
1 to 10 mN s/m2	50 – 70 kN/m2

*Gas and Vapors

High vacuum	0.4-0.8 kN/m2
Medium vacuum	0.1 x absolute pressure
1 to 2 bar	0.5 x system gauge pressure
Above 10 bar	0.1 x system gauge pressure

- Fluid Physical Properties

Alternatively, the method suggested by Frank (1978) can be used :

$$Q = \frac{A\,[U2(T1 - t2) - U1(T2 - t1)]}{\ln\left[\frac{U2(T1 - t2)}{U1(T2 - t1)}\right]}$$

(A) All Heat Exchanger Types

(a) Operating temperature

The operating temperatures of the exchanger are usually set by process conditions. However, in certain cases, the exchanger designer will establish the operating temperatures. In a typical refinery or petrochemical plant, exchangers may be operating at temperatures as high as 1000°F or as low as -200°F. These limits are dictated by material considerations, safety, economics and ASME Code requirements.

(b) Effective temperature difference

The driving force for heat transfer is the “effective temperature difference," LMTD, between the hot and cold fluids. This temperature difference is calculated from the counter-current log mean temperature difference with a correction factor applied to account for the actual flow arrangement.

Temperature approach

Temperature approach is the difference of the hotside and coldside fluid temperatures at any point within a given exchanger. A temperature cross indicates a negative driving force for heat transfer between the fluids. It requires either a large area for heat transfer or high fluid velocities to increase the overall heat transfer coefficient. If outlet temperatures form a cross in a multi-tube pass heat exchanger, a lower than desirable LMTD correction factor will occur. A simple way to avoid this is to use more exchanger shells in series.

(c) Fouling factors

The increased resistance to both heat transfer and fluid flow caused by deposits on a heat transfer surface is called fouling.

Fouling works as an insulating layer on the heat transfer surface, reducing heat transfer efficiency (reduced duty) or decreasing available flow area (reduced throughput). The increased resistance to heat transfer is represented by a quantity referred to as the fouling thermal resistance, which is added to the total thermal resistance. The values of fouling thermal resistance have generally been observed to increase with time. To account for the effect of fouling on pressure drop requires an estimate of the fouling layer thickness.

Table 1: Typical Values of Fouling Coefficient and Resistances

Fluid	Coefficient ($W.m^{-2}.C^{-1}$)	Resistance ($m^2.^oC.W^{-1}$)
River water	3000-12,000	0.0003-0.0001
Sea water	1000-3000	0.001-0.0003
Cooling water (towers)	3000-6000	0.0003-0.00017
Towns water (soft)	3000-5000	0.0003-0.0002
Towns water (hard)	1000-2000	0.001-0.0005
Steam condensate	1500-5000	0.00067-0.0002
Steam (oil free)	4000-10,000	0.0025-0.0001
Steam (oil traces)	2000-5000	0.0005-0.0002
Refrigerated brine	3000-5000	0.0003-0.0002
Air and industrial gases	5000-10,000	0.0002-0.0001
Flue gases	2000-5000	0.0005-0.0002
Organic vapors	5000	0.0002
Organics liquids	5000	0.0002
Light hydrocarbons	5000	0.0002
Heavy hydrocarbons	2000	0.0005
Boiling organics	2500	0.0004
Condensing organics	5000	0.0002
Heat transfer fluids	5000	0.0002
Aqueous salt solutions	3000-5000	0.0003-0.0002

(d) Pressure drop

The pressure drop through an exchanger is made up of three losses: the frictional loss due to flow, the losses due to changes in direction of flow and losses due to expansion and contraction into and out of nozzles and tubes. In some exchangers, a change in the vertical elevation of the fluid as it passes through the exchanger may cause a hydrostatic pressure loss or gain.

(B) Shell and Tube Exchangers

(a) Determination of number of shells based on graphical method as following.

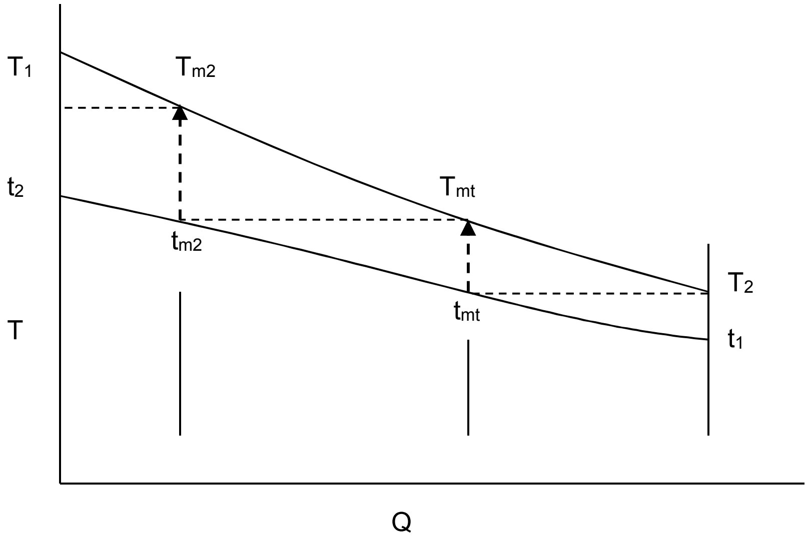


Figure 7: Temperature Profile of Two Fluid vs Heat Transfer.

(b) Tube Selection

- Type
- Length
- Diameter and wall thickness
- Ferrules

Table 2: Guidelines for Placing the Fluid in Order of Priority

Tube-side fluid	*Shell-side fluid*
Corrosive fluid	Condensing vapor (unless corrosive)
Cooling water	Fluid with large temperature difference (>40ºC)
Fouling fluid	
Less viscous fluid	
High-pressure steam	
Hotter fluid	

Table 3: Features of Shell and Tube Type Exchanger

Shell and Tube Exchanger	Typical code	Advantages	Limitations
Fixed tube sheet	BEM, AEM, NEN	Provides maximum heat transfer area for a given shell and tube diameter. Provides for single and multiple tube passes to assure proper velocity. Less costly than removable bundle designs.	Shell side / outside of the tubes are inaccessible for mechanical cleaning. No provision to allow for differential thermal expansion developed between the tube and the shell side. This can be taken care by providing expansion joint on the shell side.
Floating head	AEW, BEW, BEP, AEP, AES, BES	Floating tube sheet allows for differential thermal expansion between the shell and tube bundle. Both the tube bundle and the shell side can be inspected and cleaned mechanically.	To provide the floating-head cover it is necessary to bolt it to the tube sheet. The bolt circle requires the use of space where it would be possible to place a large number of tubes. Tubes cannot expand independently so that huge thermal shock applications should be avoided. Packing materials produce limits on design pressure and temperature.
U-tube	BEU, AEU	U-tube design allows for differential thermal expansion between the shell and the tube	Because of U-bend some tubes are amitted at the centre of the tube bundle.

		bundle as well as for individual tubes. Both the tube bundle and the shell side can be inspected and cleaned mechanically. Less costly than floating head or packed floating head designs.	Because of U-bend, tubes can be cleaned only by chemical methods. Due to U-tube nesting, individual tube is difficult to replace. No single tubes pass or true countercurrent flow is possible. Tube wall thickness at the U-bend is thinner than at straight portion of the tubes. Draining of tube circuit is difficult when positioned with the vertical position with the head side upward.

Table 4: Determination of Number of Tube Passes Based on Shell ID.

Shell ID		Recommended Maximum Number of Tube Passes
In	mm	
<10	< 254	4
10 - < 20	254 - < 508	6
20 - < 30	508 - < 762	8
30 - < 40	762 - < 1016	10
40 - < 50	1016 - < 1270	12
50 - < 60	1270 - < 1524	14

(c) Tube Site Flow

Whichever fluid appears higher on the following list will ordinarily be passed through the tubes:

(i). Cooling water.

(ii). Corrosive fluid or a fluid likely to deposit coke, sediment or other solids.
(iii). Fouling fluid, which the fluid can cause fouling.
(iv). Fluid with the less viscosity.
(v). The fluid under higher pressure
(vi) The hotter fluid.
(vii) Less volume fluid.

(d) Fluid velocity –

Liquid - Tube side: 3 – 7 ft/s and maximum is 13 ft/s if need to reduce fouling;
Water is 5 – 8 ft/s.
Shell side: 1 – 3 ft/s
Vapour – Vacuum: 164 – 230ft/s; Atmospheric: 33 - 98ft/s; High pressure:16 – 33ft/s

DEFINITION

Baffle- A device to direct the shell side fluid across the tubes for optimum heat transfer by difference of baffle cut %.

Condenser - A vessel use to change a fluid stream from the vapor state to the liquid state by removing the heat of vaporization. The fluid stream can be a pure component or a mixture of components. Condensation may occur on the shell side or the tube side of an exchanger oriented vertically or horizontally.

Cooler - Commonly is an insulated box, used to keep food or drink cool. Ice cubes which are very cold are most commonly placed in it to make the things inside stay cool. Ice packs are sometimes used, as they either contain the melting water inside, or have a gel sealed inside that also stays cold longer than plain water.

Expansion Joint “J” Factor- Is the ratio of the spring rate of the expansion joint to the sum of the axial spring rate of the shell and the spring rate of the expansion joint.

Fouling - The increased resistance to both heat transfer and fluid flow caused by deposits on a heat transfer surface. Fouling works as an insulating layer on the heat transfer surface, reducing heat transfer efficiency (reduced duty) or decreasing available flow area (reduced throughput). The increased resistance to heat transfer is represented by a quantity referred to as the fouling thermal resistance, which is added to the total thermal resistance. The values of fouling thermal resistance have generally been observed to increase with time. To account for the effect of fouling on pressure drop requires an estimate of the fouling layer thickness.

Heater -A heater is any object that emits heat or causes another body to achieve a higher temperature. In a household or domestic setting, heaters are commonly used to generate heating

Knock-Back Condenser- An apparatus and method useful for partially condensing vapor in the upper section of a fractionation tower to separate and remove a lighter gaseous fraction from a condensed liquid component, such as nitrogen from natural gas. A down flow, knockback condenser is disclosed that utilizes a vapor riser to introduce a flow of vapor into a headspace above a vertical tubular heat exchanger, thereby establishing a down flow of condensed liquid and a lighter gaseous fraction through the heat exchange tubes.

Nozzle – Nozzles are the pipe sections use to connect to the heat exchanger headers to the piping.

Pump around Coolers- Pumparound coolers cool a side stream from an intermediate tray of a distillation column. The side stream or pumparound, after it has been cooled, is returned to another tray in the distillation column. A part of the pumparound may be drawn as side stream product.

Reboiler - are heat exchangers typically used to provide heat to the bottom of industrial distillation columns. They boil the liquid from the bottom of a distillation column to generate vapors which are returned to the column to drive the distillation separation.

Steam Generator - a device used to boil water to create steam. It may refer to Boiler, a closed vessel in which water is heated under pressure ; Steam generator (nuclear power), a heat exchanger in a pressurized water reactor equipped nuclear power plant; Steam generator (railroad), a device used in trains to provide heat to passenger cars.

Superheater- is a device in a steam engine that heats the steam generated by the boiler again, increasing its thermal energy and decreasing the likelihood that it will condense inside the engine. Superheaters increase the efficiency of the steam engine, and were widely adopted. Steam which has been superheated is logically known as superheated steam; non-superheated steam is called saturated steam or wet steam. Superheaters were applied to steam locomotives in quantity from the early 20th century, to most steam vehicles, and to stationary steam engines including power stations.

Support Plate- Is a device to support the bundle or to reduce unsupported tube span without consideration for heat transfer.

Tubesheet - Is the barrier between the shell and tube fluids, and where it is essential for safety or process reasons to prevent any possibility of intermixing due to leakage at the tube sheet joint.

Vaporizer -A vaporizer is an exchanger that converts liquid into vapor. This term is sometimes limited to units handling liquids other than water.

NOMENCLATURE

A	Effective surface area (outside), ft^2
a	Tube row spacing factor, dimensionless
A_o	Surface area outside (tube), ft^2
A_i	Surface area inside (tube), ft^2
As	Effective heat transfer area per shell, ft^2
A_T	Single tube outside surface area per unit length ft^2/ft
C_p	Fluid specific heat, Btu/Ib^{o}F
CMTD	Corrected Mean Temperature Difference
D_i	Diameter inside (tube), in
DN	Nominal nozzle I.D., in.
D_o	Diameter outside (tube), in
DOTL	Diameter of bundle outer tube limit, in.
DS	Shell I.D., in.
DSNI	Shell side inlet nozzle I.D., in.
DSNO	Shell side outlet nozzle I.D., in.
DTNI	Tube side inlet nozzle I.D., in.
DTNO	Tube side outlet nozzle I.D., in.
d	OD of root diameter of integrally finned, in
f	Non-isothermal friction factor, dimensionless
F_2	LMTD correction factor
F_s	Shell side pressure drop correction factor, dimensionless
GTTD	Greatest Terminal Temperature Difference, ^{o}F
HF	Shell side friction term, dimensionless
HM	Shell side momentum term, dimensionless
h_o	Film coefficient outside, Btu/(hr.ft^2.^{o}F)
h_i	Film coefficient inside, Btu/(hr.ft^2.^{o}F)
j	Stanton Number type heat transfer factor, dimensionless
K_e	Tube side pressure drop coefficient, dimensionless
k	Thermal conductivity of fluid, Btu/hr-ft2-°F/ft
k_m	Thermal conductivity of metal, Btu/[hr.ft^2.^{o}F)/ft]
L	Tube length, ft
l	Tube wall thickness, in

LBCC	Central baffle pitch, in.
LI	Tube flow length, in.
LMTD	Log Mean Temperature Difference, ^oF
LTTD	Least Terminal Temperature Difference, ^oF
L_e	Effective tube length, ft
N	Number of tube passes
N_f	Number of fins per inch
N_p	Number of shells in parallel
N_s	Number of shells in series
N_T	Total number of shells
N_{TP}	Number of tube passes per shell
N_{TT}	Number of tubes in a bundle
n	n^{th} zone value
n_r	Baffle spacing to bundle diameter ratio, dimensionless
p	Baffle flow factor, dimensionless
PR	Tube pitch ratio, dimensionless
PT	Tube pitch, in.
ΔP_e	Tube entrance, expansion, and turnaround pressure drop, psi
ΔP_{exch}	Total nozzle to nozzle shell side pressure drop, psi
ΔP_n	Tube side nozzle pressure drop, psi
ΔP_s	Shell side pressure drop (excluding nozzles), psi
ΔP_{sn}	Shell side nozzle pressure drop, psi
ΔP_t	Tube side frictional pressure drop, psi
$(\Delta P_t)_{nn}$	Total tube side nozzle pressure drop, psi
Q	Heat transferred, Btu/hr
R	Sum of resistances, (hr.ft^2.^{o}F)/ Btu
Rc	Total resistance (clean) to heat transfer, (hr-ft^2-°F)/Btu
Re	Reynolds Number, dimensionless
Re_{xt}	Shell side total flow Reynolds Number, dimensionless
Re_{xh}	Cross flow Reynolds number for heat transfer, dimensionless
Re_{xp}	Cross flow Reynolds Number for pressure drop, dimensionless
r_{fo}	Fouling resistance outside (shell), (hr.ft^2. ^{o}F)/Btu
r_I	Inside fouling factor to inside surface area, hr-ft^2-°F/Btu
r_{fi}	Fouling resistance inside (tube) referred to outside surface area,, ((hr.ft^2. ^{o}F)/Btu)

r_w	Metal resistance for tube, (hr.ft^2. ^{o}F)/Btu
SC	Baffle spacing correction factor, dimensionless
S_{TT}	Tube sheet material allowable stress at design temperature, lb/in^2.
ΔT	Fluid temperature change, ^{o}F
TS_b	Bulk temperature of shell side fluid, °F
TT_b	Bulk temperature of tube side fluid, °F
TTT	Total tube sheet thickness, ft
U	Overall heat transfer coefficient, Btu/hr^{o}F.ft^2
U_c	Clean coefficient, Btu/hr^{o}F.ft^2
U_D	Calculated overall fouled coefficient of heat transfer, Btu/hr-ft^2-°F
U_o	Overall duty coefficient of heat transfer, Btu/hr-ft^2-°F
V_n	Tube side average nozzle fluid velocity, ft/sec
V_t	Fluid velocity in tubes, ft/sec
W	Fluid flow rate, lb/hr
W_s	Shell side mass rate per shell, lb/hr
w	Fin height, in
WTD	Weighted temperature difference, ^{o}F

Greek letters

λ	Latent heat of specific fluid, Btu/lb
ϕ	Viscosity correction for wall temperature, dimensionless
μ_b	Viscosity at bulk temperature, centipoise
μ_W	Viscosity at wall temperature, centipoise
ξ	Baffle correction factor, dimensionless
ρ	Density, lb/ft^3