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KLM Technology Group #03-12 Block Aronia, Jalan Sri Perkasa 2 Taman Tampoi Utama 81200 Johor Bahru Malaysia	PROCESS REQUIREMENTS OF HEAT EXCHANGING EQUIPMENT (PROJECT STANDARDS AND SPECIFICATIONS)	

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PROCESS DESIGN OF PLATE HEAT EXCHANGERS (PLATE FIN EXCHANGERS)

SCOPE

This Project Standards and Specifications covers the minimum process design requirements, for thermal design, field of application, selection of types and hydraulic calculations for shell and tube heat exchangers, and plate heat exchangers (plate fin exchangers).

REFERENCES

Throughout this Standard the following dated and undated standards/codes are referred to. These referenced documents shall, to the extent specified herein, form a part of this standard. For dated references, the edition cited applies. The applicability of changes in dated references that occur after the cited date shall be mutually agreed upon by the Company and the Vendor. For undated references, the latest edition of the referenced documents (including any supplements and amendments) applies.

1. TEMA (The Tubular Exchanger Manufacturers Association)

	"Standards of the Tubular Exchanger Manufacturers Association (TEMA)" 9th Ed.2007

2. API (American Petroleum Institute)

API Std. 660,	"Shell & Tube Heat Exchangers for General Refinery Services" for General Refinery Services" 7th. Ed., April 2003, Reaffirmed Dec. 1987
API Std. 662 Part I-	"Plate Heat Exchanger for General Refinery Services" Plate-and Frame Heat Exchangers 1st.Ed.Feb.2006
API Std. 662 Part II-	"Plate Heat Exchanger for General Refinery Services" Brazed Aluminum Plate –Fin Heat Exchangers 1st.Ed.Feb.2006

DEFINITIONS AND TERMINOLOGY

Chiller - The chiller is a typical kettle type exchanger, and the bundles has tubes to a height of about 60 per cent of the diameter. The vapor space above is for disengagement of the vapor from the liquid. Chillers are used in refrigeration processes of the vapor-compression type. A chiller cools a fluid with a refrigerant to a temperature below that obtainable using air or cooling water as the heat sink. Common refrigerants are propane, ethylene and propylene; chilled water or brines are less frequently used.

Condenser - A condenser is a unit in which a process vapor is totally or partially converted to liquid. The heat sink is ordinarily a utility, such as cooling water. The term "surface condenser" refers specifically to shell and tube units, used to condense the steam from a preceding ejector stage, thus reducing the inlet quantity of vapor mixture to the following stage. This is a means of increasing steam economy. They do not affect ejector performance, but they do avoid the nuisance of exhausting steam to the atmosphere, thus, they allow steam to be recovered. A "direct contact condenser" refers to a unit in which the vapor is condensed by direct contact heat exchange with droplets of water.

- **Surface condenser -** Surface condenser is to condense the exhaust steam from a steam turbine to obtain maximum efficiency and also to convert the turbine exhaust steam into pure water (referred to as steam condensate) so that it may be reused in the steam generator or boiler as boiler feed water.
  - **Purpose** - Surface condenser by condensing the steam exhaust of a turbine at a pressure below atmospheric pressure, the pressure drop between the inlet and exhaust of the turbine is increased, which increases the amount of heat available for conversion to mechanical power.
  - **Cooling medium -** Most of the heat liberated due to condensation of the exhaust steam is carried away by the cooling medium (water or air) used by the surface condenser.
  - **Shell -** For most water-cooled surface condensers, the shell is under vacuum during normal operating conditions. Surface condenser shell is fabricated from carbon steel plates and is stiffened as needed to provide rigidity for the shell. When required by the selected design, intermediate plates are installed to serve as baffle plates that provide the desired flow path of the condensing steam.
  - **Hotwell -** At the bottom of the shell, where the condensate collects, an outlet is installed. In some designs, a sump (often referred to as the hotwell) is provided. Condensate is pumped from the outlet or the hotwell for reuse as boiler feed water.
  - **Vacuum system -** For water-cooled surface condenser, the shell's internal vacuum is mostly commonly supplied by and maintained by an external steam jet ejector system. Such an ejector system uses steam as the motive fluid to remove any non-condensible gases that may be present in the surface condenser.

    Motor driven mechanical vacuum pumps such as liquid ring type vacuum pumps, are also popular for vacuum service.

- **Tube sheets -** At each end of the shell, a sheet of sufficient thickness usually made of stainless steel is provided, with holes for the tubes to be inserted and rolled.
- **Tubes -** Generally the tubes are made of stainless steel, copper alloys such as brass or bronze, cupro nickel or titanium depending on several selection criteria. The use of copper bearing alloys such as brass or cupro nickel is rare in new plants, due to environmental concerns of toxic copper alloys. Also depending on the steam cycle water treatment for the boiler, it may be desirable to avoid tube materials containing copper. Titanium condenser tubes are usually the best technical choice; however, the use of titanium condenser tubes has been virtually eliminated by the sharp increase in the cost for this material.

  The outer diameter of condenser tubes typically ranges from 19mm (¾ inch) to 32mm (1-1/4 inch), based on condenser cooling water friction consideration and overall condenser size.
- **Waterboxes -** The tube sheet at each end with tube ends rolled for each end of the condenser is closed by a fabricated box cover known as waterbox, with flanged connection to the tube sheet or condenser shell. The waterbox is usually provided with manholes on hinged covers to allow inspection and cleaning.
- **Codes -** Steam surface condensers operate under a vacuum and are, therefore, not considered pressure vessels. The ASME Code is a pressure vessel code and is not, Strictly speaking, applicable to surface condensers operating under vacuum. However, the tube side of a surface condenser is considered a pressure vessel, as it is subjected to the full water pressure. When necessary, this side of the condenser can be designed and constructed to ASME Code requirement.

  Most surface condensers are designed and constructed in accordance with HEI Standards.

Cooler - A cooler exchanges heat between a process stream and water or air.

Evaporator - Exchangers specifically designed to process fluid by some heating medium such as steam.

Exchanger and/or heat exchanger - In the broad sense, an exchanger is any item of unfired heat transfer equipment whose function is to change the total enthalpy of a stream. In the specific (and more usual) connotation, an exchanger transfers heat between two process streams.

Fouling resistance - The fouling resistance is a measure of the ultimate additional resistance to heat transfer caused by deposits on and corrosion of the heat transfer material surface.
Note: The resistance depends on the type of fluid, the material, temperature conditions, flow velocities and the operating period between two successive cleaning actions.

Fouling coefficient - The fouling coefficient is the reciprocal of the fouling resistance.
Note: The use of the fouling coefficient has generally been abandoned, since it tends to be confusing that an increase in fouling results in a decrease in fouling coefficient.

Reboiler - reboiler is a vaporizer that provides latent heat of vaporization to the bottom (generally) of a fractionation tower.There are two general classes of reboilers, those which send both phases to the tower for separation of vapor from liquid and those which return only vapor. The former operate by either natural circulation (usually called thermosyphon) or forced circulation.

- Thermosyphon reboilers are by far the common type. Horizontal thermosyphons with vaporization on the shell side are commonly used in the petroleum industry while vertical units with in-tube vaporization are favored in the chemical industry. In a thermosyphon reboiler, sufficient liquid head is provided so that natural circulation of the boiling medium is maintained.
- Forced circulation reboilers require a pump to force the boiling medium through the exchanger. This type of reboiler is infrequently used because of the added cost of pumping the reboiler feed, but may be required to overcome hydrostatic head limitations and/or circulation problems.
- Reboilers which return only vapor to the tower are called kettle reboilers. The operation of kettle reboilers would be best described as pool boiling.

Steam generators (waste heat boilers) - Steam generators are a special type of vaporizer used to produce steam as the vapor product. Generally, the heat source is excess heat beyond that which is required for process; this accounts for the common name of "waste heat boiler" for these Units. Like reboilers, steam generators can be kettle, pump-through, or thermosyphon type.

Superheater - A superheater heats a vapor above its saturation temperature.

TEMA "Class R" exchanger - The TEMA Mechanical Standards for "Class R" heat exchanger specify design and fabrication of unfired shell and tube heat exchangers for the generally severe requirements of petroleum and related process application.

TEMA "Class C" exchanger - The TEMA Mechanical Standards for "Class C" heat exchangers specify design and fabrication of unfired shell and tube heat exchangers for the generally moderate requirements of commercial and general process application. "Class C" units are designed for maximum economy and result in a cost saving of about 5% over "Class R".

TEMA "Class B" exchanger - The TEMA Mechanical Standards for "Class B" heat exchangers specify design & fabrication of unfired shell & tube heat exchangers for chemical process service.

Vaporizor - A vaporizor is an exchanger which converts liquid into vapor. This term is sometimes limited to units handling liquids other than water.

SYMBOLS AND ABBREVIATIONS

SYMBOL/ABBREVIATION	DESCRIPTION
A	Total exchanger area, (m^2).
A_i	Required effective inside transfer surface, (m^2).
API	American Petroleum Institute.
Btu	British Thermal Unit.
CAF	Compressed Asbestos Fiber
DEA	Di – Ethanol Amine.
DGA	Di - Glycol Amine.
DN	Diameter Nominal, (mm).
DS	Design Pressure.
DS	Diameter of shell
EPDM	Ethylene Propylene Di Monomer.
F	LMTD Correction Factor
FPM	Fine Particular Matter.
H	Segment Opening Height
h_f	Film coefficient of tube side fluid, in ($W/m^2.°C$) or ($W/m^2.K$)
ID	Inside Diameter, in (mm).
LMTD	Logarithmic Mean Temperature Difference.
MAWP	Maximum Allowable Working Pressure.

Max.	Maximum.
MEA	mono-Ethanolamine.
Min.	Minimum.
MOP	Maximum Operating Pressure.
MOT	Maximum Operating Temperature.
OD	Outside Diameter, (mm).
OGP	Oil, Gas and Petrochemical.
OP	Operating Pressure
PHE	Plate Heat Exchanger.
PSV	Pressure Safety Valve.
r_i	Fouling resistance on inside surface of tubes, ($m^2.°C/W$).
r_o	Fouling resistance on outside surface of tubes, ($m^2.°C/W$).
RCB	Resin Cured Butyl.
RGP	Recommended Good Practice.
SS	Stainless Steel.
TEMA	Tubular Exchanger Manufacturers Association.
V	Linear Velocity of the fluid, (m/s).
U	The overall heat transfer coefficient, ($W/m^2.°C$) or ($W/m^2.K$)
WC	Water Column, (mm).
ρ(rho)	Density, (kg/m^3).

UNITS

This Standard is based on International System of Units (SI) except where otherwise specified.

PROCESS DESIGN OF SHELL AND TUBE HEAT EXCHANGERS

General Considerations

1. The shell and tube type exchanger is commonly used in general petroleum processes. It is inexpensive, easy to clean, available in many sizes, and can be designed for moderate to high pressures at reasonable cost. It consists of a bundle of tubes encased in a shell.

2. Tubular units in general should have removable tube bundles and should be of the floating head type with removable shell covers.

   Typical exceptions are:

   a. Fixed tube sheet exchangers such as refrigeration condensers and vacuum condensers.

      In this type of construction, differential expansion of the shell and tubes due to different operating metal temperatures may require the use of an expansion joint or a packed joint.

   b. "U" tube type for reboilers using steam in the tube and for exchangers on hydrogen service. Removable shell covers are not required for this type.

   Fluids having a fouling factor above -0.00035m².K/W(0.002 hr.ft².°F/Btu) should be routed on the shell side of U-tube exchangers and on the tube side for floating head type exchangers. In all cases U-tubes should be located in the horizontal plane.

   For chemical works, fixed head exchangers should be used when the shell side fluid is nonfouling. Where the shell side fluid is fouling. Utubes or floating head type bundles should be used and floating head type tube bundles when both sides are fouling.

   Floating head type tube bundles are to be avoided for kettle type reboilers and chillers unless agreed by the Company.

3. There are two variations of floating tube sheet units, the pull-through and the non-pull-through. In the pullthrough unit, the entire floating tube sheet and cover assembly may be drawn through the shell without disassembly. In the non-pullthrough unit, the shell cover and the floating tube sheet cover must be removed before the bundle can be taken out of the shell.

   This requirement is the greatest disadvantage of the non-pull-through unit. However, due to the smaller diameter tube sheet which is possible if a split ring assembly is used to fasten the floating head cover, the non-pull-through unit requires a smaller shell for the same surface.

4. Listing the above variations in shell and tube units in order of increasing cost would give the following tabulation:
   a. Simple fixed tube sheet unit.
   b. U-tube unit.
   c. Fixed tube sheet unit with an expansion joint or packed joint.
   d. Floating tube sheet unit (pull-through and non-pull-through).

   Shell and tube type exchangers are usually fabricated to conform to "Class R" of the Standards of the Tubular Exchanger Manufacturers Association (TEMA).

5. The selection of TEMA "Class R" or TEMA "Class C" exchangers shall be governed by the following:
   a. TEMA "R" is required when:
      - Tube side or shell side fouling factor is greater than 0.00035 $m^2.K/W$; or
      - Shell side corrosion allowance is greater than 3.175 mm (1/8 inch);
      - Shell side corrosion rate is greater than 0.254 mm/y (10 mils per year).
   b. TEMA "C" may be used when exchanger is designed for chemical cleaning maintenance and fouling factor do not exceed 0.00035 $m^2.K/W$ on both tube side and shell side.

6. Horizontal and Vertical Exchangers

   Heat exchangers should be of the horizontal type, however, for process requirements and where cleaning and other maintenance will be infrequent and space requirements make it more attractive, the vertical arrangement may be considered and this should be discussed with the Company. Centerline elevation of the top bundle of stacked exchangers shall be limited to 3.5 m except for large exchangers which shall be limited to two stacked shells.

   When horizontal arrangements are preferred, the stacking of exchangers should be considered to conserve space in the structure.

7. The Use of Spiral Plate Heat Exchangers May be Considered When:
   a. Small overhead or vent condensers mounted directly on process vessels are required.
   b. Space limitations make use of long shell and tube units impractical.

8. Manufacturer's standard for shell and tube heat exchangers may be considered upon approval of the Company and supplied as components of other equipment such as:

   a. Compressor inter/after coolers.

   b. Steam ejector inter/after condensers.

   c. Machinery lube oil coolers.

   Fig. A.1 in Appendix A shows different types of shells which has been extracted from TEMA.

9. Selection Guide for Heat Exchanger Types

   Table B.1 in Appendix B is also selection guide for heat exchanger types which shows significant feature, applications best suited, limitation and relative cost in carbon steel construction of heat exchangers.

10. Selection of Type

    Fixed tube sheet heat exchangers should only be used in services where:

    - Differential expansion between the tubes and the shell does not give rise to unacceptable stresses;
    - Tube side cleaning, if required, can be don in situ;
    - Shell side fluid is non-fouling, or
    - Shell side fouling can be removed by chemical cleaning.

    U-tube bundle heat exchangers shall only be used in services where:

    - Tube side fouling resistance is less than 0.00035 (m^2.K)/W;
    - Tube side fouling can be removed by chemical cleaning.

    U-tube shall not be applied when tube side mechanical cleaning is required.

    Floating head heat exchangers should be used in all other services except as noted above,

11. Shell Selection

    a. The single-pass shell, Type E (see Fig. A.1 in Appendix A), has the widest application and should be selected for general duties, except where significant advantage can be obtained by using one of the other shell types.

    b. Where the shell side pressure drop is a restricting factor, the divided flow shell Type J or cross flow shell Type X or double-split flow shell Type H, should be considered.

c. For horizontal shell side thermosiphon reboilers, the split flow shell Type G or Type H should be selected.
d. The kettle type, shell Type K, should be selected for boiling, where an almost 100% vaporization, or where a phase separation is required.
e. Use of the two-pass shell with longitudinal baffle Type F, should be avoided.

12. Front End and Rear End Selection

a. Front end bonnet Type B is generally used for heat exchangers where cleaning on the tube side will be infrequent.

   Rear end Type S should be used for floating head heat exchangers.
b. Rear end Type M should be applied for fixed tube sheet design.
c. When frequent tube side cleaning is anticipated, and the tube design pressure is low, the front end stationary head shall be Type A, however, for the corresponding rear end, Type may be selected.
d. For high-pressure and/or very toxic service, where it is desirable to limit the number of external joints, stationary heads Type B, Type C or Type N should be selected for the front end, and the corresponding Type M or Type N for the rear end.
e. The outside packed floating head Type P, and externally sealed floating tubesheet type W rear ends, are not acceptable.

13. Water-Cooled Coolers

The following restrictions shall apply to water-cooled coolers:

a. Cooling water shall run upwards through the tubes in order to avoid build up of gas. The tube side velocity shall be as specified in Table 1.
b. The tube side shall be maintained at an atmospheric over-pressure so that air cannot separate from the water.
c. In open cooling water systems, the cooling water outlet temperature shall not be higher than 42°C, and to avoid scaling, the tube wall temperature on the cooling water side shall not exceed 52°C.
d. Internal bellows shall not be applied.
e. In fouling services, the following additional restrictions apply:
   - In cases where flow control of the water is required, tube side velocities should not be allowed to fall below the values specified in Table 1, in order to avoid deposits of mud, silt or salt.
   - U-tubes shall not be applied.
f. Shell and tube exchangers using water as the cooling medium are to be avoided when product side temperatures exceed 200°C.

GENERAL REQUIREMENTS

Fluid Allocation

1. Fluid allocation shall be made under the following conditions. Dirty fluids are passed thorough the tubes because they can be easily cleaned, particularly if the tube bundle cannot be removed, but through the shell if the tubes cannot be cleaned (hair pin bundles) or if large amounts of coke or debris are present which can be accumulated in the shell and removed by dumping the shell.
2. High pressure fluids, corrosive stock, and water are sent through the tubes because the strength of small-diameter (and thin) tube surpasses that of the shell, because corrosionresistant tubes are relatively cheap, and because corrosion or water scale can be easily removed.
3. For the same pressure drop, higher heattransfer coefficients will be obtained on the tubeside than the shell-side.
4. Large volume fluids (vapors) are passed through the shell because of the availability of adequate space, but small volume fluids are also passed through the shell where cross baffles can be used to increase the transfer rates without producing an excessive pressure drop.
5. Vapors that contain non-condensable gases are sent through the tubes so that the accumulation of noncondensables will be swept out.
6. If the pressure drop must be low, the fluids are sent through the shell. The same applies to viscous or low transfer rate fluids because the maximum transfer rates for a fixed pressure drop can be obtained by the use of cross baffles in the shell.
7. In fin tube equipment, high-pressure, dirty, or corrosive stock is sent through the fin tube because it is relatively cheap, can be easily cleaned, and has a higher strength than the outside tube.
8. Condensing steam is normally passed through the tubes.
9. If the temperature change of one fluid is very large (greater than approximately 145°C to 175°C), that fluid is usually passed through the shell, rather than the tubes, if more than one tube pass is to be used. This minimizes the construction problems caused by thermal expansion. Also, to avoid thermal stress problems, fluids with greater than 175°C temperature change cannot be passed through the shell side of a two pass shell.

   If the temperatures are high enough to require the use of special alloys placing the higher temperature fluid in the tubes will reduce the overall cost.

At moderate temperatures, placing the hotter fluid in the tubes will reduce the shell surface temperatures, and hence the need for lagging to reduce heat loss, or for safety reasons.

10. If one of the fluids is clean (fouling factor 0.00017 m².°C/W) and is only mildly corrosive to the material selected this fluid is passed through the tubes and U-tube construction is used, where economical.
11. 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 certainty.

Installation

1. Vertical
    a. Condensate subcooling may be accomplished more easily in a vertical unit.
    b. For boiling fluids, this is usually a single tube pass type with vaporization occurring in the tubes.
2. Inclined

    For tube side condensing fluids, this type of heat exchanger is sometimes employed to ensure positive drainage of the condensate from the tube. Even a few degrees inclination from the horizontal prevents the accumulation of condensate and possible redistribution, flooding, and surging effects.
3. Horizontal

    Others.

Nozzle Location

The following rules are suggested as a guide for locating heat exchanger nozzles:

1. Streams being heated or vaporized should flow from bottom to top, whether on the tube side or the shell side.

2. Streams being condensed should flow from top to bottom, whether on the tube side or the shell side.
3. The direction of flow of streams being cooled should be dictated by piping economics.

Impingement Baffles and Erosion Protection

The following paragraphs should provide limitations to prevent or minimize erosion of tube bundle components at the entrance and exit areas. These limitations have no correlation to tube vibration and the designer should refer to Section 6 of TEMA for information regarding this phenomenon.

1. Shell side impingement protection requirements

   An impingement plate, or other means to protect the tube bundle against impinging fluids, shall be provided when entrance line values of ρ V2 exceed the following: non-corrosive, nonabrasive, single phase fluids, 2230: all other liquids, including a liquid at its boiling point, 744. For all other gases and vapors, including all nominally saturated vapors, and for liquid vapor mixtures, impingement protection is required. V is the linear velocity of the fluid in meter per second and ρ is its density in kg per cubic meter. A properly designed diffuser may be used to reduce line velocities at shell entrance.

2. Shell or bundle entrance and exit areas

   In no case shall the shell or bundle entrance or exit area produce a value of ρ V2 in excess of 5950 where V is the linear velocity of the fluid in meter per second and ρ is its density in kilogram per cubic meter.

   a. Shell entrance or exit area with impingement plate

      When an impingement plate is provided, the flow area shall be considered the unrestricted area between the inside diameter of the shell at the nozzle and the face of the impingement plate.

   b. Shell entrance or exit area without impingement plate

      For determining the area available for flow at the entrance or exit of the shell where there is no impingement plate, the flow area between the tubes within the projection of the nozzle bore and the actual unrestricted radial flow area from under the nozzle or dome measured between the tube bundle and shell inside diameter may be considered.