PIP VECST001
Supplemental Design Criteria and Purchasing Requirements for Shell and Tube Heat Exchangers
ASME Code Section VIII, Divisions 1 and 2
PURPOSE AND USE OF PROCESS INDUSTRY PRACTICES

In an effort to minimize the cost of process industry facilities, this Practice has been prepared from the technical requirements in the existing standards of major industrial users, contractors, or standards organizations. By harmonizing these technical requirements into a single set of Practices, administrative, application, and engineering costs to both the purchaser and the manufacturer should be reduced. While this Practice is expected to incorporate the majority of requirements of most users, individual applications may involve requirements that will be appended to and take precedence over this Practice. Determinations concerning fitness for purpose and particular matters or application of the Practice to particular project or engineering situations should not be made solely on information contained in these materials. The use of trade names from time to time should not be viewed as an expression of preference but rather recognized as normal usage in the trade. Other brands having the same specifications are equally correct and may be substituted for those named. All Practices or guidelines are intended to be consistent with applicable laws and regulations including OSHA requirements. To the extent these Practices or guidelines should conflict with OSHA or other applicable laws or regulations, such laws or regulations must be followed. Consult an appropriate professional before applying or acting on any material contained in or suggested by the Practice.

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# PIP VECST001
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1. **Scope**

This Practice provides requirements for use by a Purchaser for determining the design criteria including design, materials of construction, inspection and testing for shell-and-tube heat exchangers constructed in accordance with ASME *Boiler and Pressure Vessel Code*, Section VIII, Division 1 or Division 2, henceforth referred to as the *Code*, TEMA *Standards of the Tubular Exchangers Manufacturers Association*, and *PIP VECV1001*. Requirements that are specific to *Code*, Section VIII, Division 2 are shown in braces { }. This Practice provides requirements for purchasing shell-and-tube heat exchangers that are to be designed and fabricated by a Manufacturer. This Practice also provides guidance for the development of purchase specifications for the construction of new shell-and-tube heat exchangers which meet the philosophy and requirements of *Code*, Section VIII, Division 1 {or 2} and *PIP VECV1001*.

For some heat exchanger purchases, certain requirements in this Practice and in *PIP VECV1001* may be assigned by Purchaser to Manufacturer. The specific requirements assigned (e.g., thermal design and the performance rating) can be specified on Purchaser’s *PIP VEDST003* Data Sheet.

The following are not covered by this Practice:

a. Standardized pre-designed (i.e., off-the-shelf) shell-and-tube heat exchangers (see *PIP VESSM001*)

b. Hairpin heat exchangers (see *PIP VESHP001*)

2. **References**

Applicable parts of the following Practices, industry codes and standards, and references shall be considered an integral part of this Practice. The edition in effect on the date of contract award shall be used, except as otherwise noted. Short titles are used herein where appropriate.

2.1 **Process Industry Practices (PIP)**

- *PIP VECV1001* - *Design and Fabrication of Pressure Vessels, ASME Section VIII, Divisions 1 and 2*
- *PIP VESV1002* - *Design and Fabrication Specification for Vessels, ASME Code Section VIII, Divisions 1 and 2*
- *PIP VEDST003* - *Shell and Tube Heat Exchanger Specification Sheet*
- *PIP VEFV1100* - *Vessel/S&T Heat Exchanger Standard Details*
- *PIP VEFV1132* - *Minimum Clearance for Nozzle Adjacent to Integral Tubesheet*
- *PIP VESHP001* - *Hairpin Heat Exchanger Specification*
- *PIP VESSM001* - *Specification for Small Pressure Vessels and Heat Exchangers with Limited Design Conditions*
- *PIP VESST002* - *Supplemental Design and Fabrication Specification for Shell and Tube Heat Exchangers, ASME Code Section VIII, Divisions 1 and 2*

2.2 **Industry Codes and Standards**

For each of the following reference documents, if *Code*, Table U-3 {1.1} lists an edition or addenda different than the edition listed in the reference, the edition listed in *Code*, Table U-3 {1.1} shall be used.
• American Society of Civil Engineers (ASCE)
  – ASCE 7 - Minimum Design Loads for Buildings and Other Structures
• American Society of Mechanical Engineers (ASME)
  – ASME Boiler and Pressure Vessel Code
    Section VIII - Pressure Vessels, Divisions 1 and 2
• Tubular Exchanger Manufacturers Association (TEMA)
  – Standards of the Tubular Exchanger Manufacturers Association

2.3 Government Regulations
• U. S. Department of Labor, Occupational Safety and Health Administration (OSHA)
  – OSHA 29 CFR 1910.146(k)(3)(ii) - Permit-Required Confined Spaces for General Industry

3. Definitions

Definitions provided in PIP VECV1001 shall apply to this Practice. The following definitions shall be used in addition to those listed in PIP VECV1001.

**Designer:** The party responsible for defining and specifying the mechanical design requirements (e.g., Heat exchanger Drawing/Data Sheet {User’s Design Specification}) consistent with User criteria for use by the Manufacturer. Typically, Designer is an engineering contractor, but may be the Owner, User, Purchaser, third party consultant, or Manufacturer. Unless otherwise specified in the purchase order, Designer is responsible for the thermal design of the heat exchanger.

**exchanger:** Shell-and-tube heat exchanger

**Purchaser:** The party responsible for placing the purchase order for the heat exchanger or heat exchanger components. Purchaser may be the Designer, Owner, User, or User’s designated agent.

4. Requirements

4.1 General

4.1.1 Shell and tube heat exchangers shall be configured and specified in accordance with the requirements of this Practice, PIP VECV1001, the Code, other standards as referenced in this Practice, local requirements, and the other contract documents furnished by the Owner.

4.1.2 The following references cited in PIP VECV1001 shall be replaced with the following references:

a. Replace “vessel” with “shell-and-tube heat exchanger”

b. Replace “PIP VEDV1003” with “PIP VEDST003”

4.1.3 This Practice shall be used in conjunction with PIP VESV1002, PIP VESST002, PIP VEDST003, and applicable details included in PIP VEFV1100 for a complete exchanger purchase specification.
4.1.4 If certain requirements of this Practice and PIP VECV1001 are to be performed by Manufacturer, the assigned requirements shall be specified on the Purchaser’s PIP VEDST003-D Data Sheet.

4.2 Exchanger Configuration Considerations

4.2.1 General

4.2.1.1 The various exchanger configurations are defined in TEMA.

4.2.1.2 Exchanger configuration significantly affects the thermal design characteristics.

4.2.1.3 The various exchanger configurations have certain advantages and disadvantages with regard to maintenance, operation, and cost.

4.2.2 Fixed Tubesheet Exchangers

4.2.2.1 Advantages of fixed tubesheet exchangers include the following:

a. Typically lowest cost design
b. No gasketed joint between tube side and shell side fluids
c. Shell side has no gasketed girth joints
d. Temperature crosses can be handled with counterflow designs
e. Low circumferential bypass area around the bundle
f. Straight tubes permit mechanical tube side cleaning

4.2.2.2 Disadvantages of fixed tubesheet exchangers include the following:

a. Shell side cannot be mechanically cleaned
b. Limited access for internal shell inspection
c. Limited differential thermal expansion permitted without the use of an expansion joint

4.2.3 U-Tube Exchangers

4.2.3.1 Advantages of U-tube exchangers include the following:

a. Typically lowest cost removable bundle design
b. No thermal expansion problems between shell and tubes
c. Removable bundle for shell side mechanical cleaning
d. Permits internal shell inspection
e. Low circumferential bypass area
f. For tube side high-alloy and high-pressure, typically lower cost than fixed tubesheet exchangers
g. No gasketed joint between tube side and shell side fluids

4.2.3.2 Disadvantages of U-tube exchangers include the following:

a. Tube side not easily mechanically cleaned
b. Only tubes at bundle periphery can be easily replaced

c. For certain baffle arrangements, can have large pass lane bypass area

d. Unless properly supported, U-bends are susceptible to vibration problems

4.2.4 **TEMA Type S Exchangers**

4.2.4.1 Advantages of *TEMA* Type S exchangers (i.e., non-pull through floating head) include the following:

a. Removable bundle permits shell side mechanical cleaning

b. No thermal expansion problems between shell and tubes

c. Straight tubes permit mechanical tube side cleaning

d. Permits internal shell inspection

4.2.4.2 Disadvantages of *TEMA* Type S exchangers include the following:

a. Higher cost

b. Internal gasketed joint

c. Larger circumferential bypass area

d. Labor intensive to pull bundle

e. For large diameter exchangers, split rings present difficulties for maintenance

4.2.5 **TEMA Type T Exchangers**

4.2.5.1 Advantages of *TEMA* Type T exchangers (i.e., pull through floating head) include the following:

a. Removable bundle permits shell side mechanical cleaning

b. No thermal expansion problems between shell and tubes

c. Straight tubes permit mechanical tube side cleaning

d. Permits internal shell inspection

4.2.5.2 Disadvantages of *TEMA* Type T exchangers include the following:

a. Highest cost

b. Internal gasketed joint

c. Largest circumferential bypass area around the bundle

d. Labor intensive to pull bundle

4.2.6 **TEMA Type F Exchangers**

4.2.6.1 Use of the *TEMA* Type F exchangers (i.e., two-pass shell) shall be approved by User.

4.2.6.2 Exchanger design shall consider the following concerns:

a. Differential pressure and temperature across the longitudinal baffle
b. Heat transfer through the longitudinal baffle

c. Flow bypassing around the removable longitudinal baffles

4.2.7 Flow Orientation

4.2.7.1 Typically, liquids shall be arranged in an upward flow direction in order to facilitate liquid filling without gas pockets.

4.2.7.2 If liquid velocities are not adequate, particulate-laden liquids (e.g., boiler water blowdown) may have a downward flow arrangement to assist in the exhaustion of solids.

4.2.7.3 Typically, two phase flows shall have the hot stream (i.e., condensing) flow downward and the cold stream (i.e., boiling) upward.

4.2.7.4 Two phase flows for “falling film evaporation” and “reflux condensation” configurations shall have liquid flow downward and vapor flow upward.

4.2.7.5 Mist flow may require flow in either down or up direction.

4.2.7.6 Gases may flow down or up in accordance with the Log Mean Temperature Difference calculation.

4.2.8 Tube Layout

4.2.8.1 Removable bundle designs, and square or rotated square tube patterns may be used for dirty shell side service. Cleaning lanes of ¼ inch (6 mm) minimum shall be provided throughout the bundle.

4.2.8.2 Triangular pattern may be used for clean shell side services, whether the bundle is removable or not.

4.2.8.3 An expanded pitch triangular design may be used in dirty services only if sufficient cleaning lanes are provided by the tube layout and if approved by User.

4.2.9 Baffles

4.2.9.1 For horizontal exchangers, horizontal cut (i.e., baffle cut perpendicular to shell nozzle axis) single segmental baffles should be used for single-phase shell side service.

4.2.9.2 For horizontal exchangers, vertical cut (i.e., baffle cut parallel to shell nozzle axis) baffles may be used to minimize liquid pooling for two-phase service.

4.2.9.3 For vertical exchangers, segmental baffles shall be cut perpendicular to the inlet flow path.

4.2.9.4 To avoid flow-induced tube vibration, the following may be considered:

   a. Modify tube field to provide no tubes in the baffle window

   b. Provide intermediate tube supports

4.2.9.5 Multi-segmental baffles (i.e., typically double, but also triple segmental) may be used to reduce the shell side pressure drop.
4.2.9.6 Special baffle designs (e.g., rod, disk and donut, longitudinal, spiral baffles) shall be approved by User.

4.2.9.7 If required to prevent acoustic vibration, “de-tuning” baffles may be used in gas service shell side.

4.2.9.8 Baffles adjacent to tube bends shall be located in the straight portion of the tubes, and not greater than 2 inches (50 mm) from the tangent line of the bends.

4.2.9.9 Peripheral tie rods and spacers for positioning baffles shall be located so that the outside of the spacers coincides with the outer periphery of the baffles. The inside diameter of the spacer shall not be greater than the outside diameter of the tie rod plus 1/8 inch (3 mm).

4.3 Mechanical Design

4.3.1 Design Pressure and Temperature

4.3.1.1 In addition to the operating phases and associated loading listed in PIP VECV1001, Section 4.2.1.1, failure of an internal pressure boundary (e.g., tube failure) shall be considered. See Code Paragraph UG-133(d) {9.1.3 a}.

4.3.1.2 Shell side and tube side design pressures and temperatures shall be reviewed to determine extreme conditions that can be encountered.

Comment: During transients (e.g., startup, pressure relief, shutdown), the shell side or tube side fluid can be absent, not flowing, or auto-refrigerating with design pressure in the other chamber.

4.3.1.3 For components subjected to both shell side and tube side conditions, the more severe condition shall control the design.

Comment: Fixed tubesheet exchangers cannot generally be operated at the coincident nameplate temperature-pressure conditions.

4.3.1.4 Exchanger components shall be designed for full pressure on either tube side or shell side with atmospheric pressure or full vacuum (if specified) on the other side.

4.3.1.5 If the Purchaser’s PIP VEDST003-D Data Sheet specifies that an exchanger is to be designed for differential pressure, the nameplate shall so indicate.

4.3.1.6 The basis for differential thermal expansion used in the design shall be shown on the Purchaser’s PIP VEDST003-D Data Sheet and on the fabrication drawings.

4.3.2 Nozzles

4.3.2.1 Placing vents and drains in a tubesheet to meet specific process needs shall be considered.

4.3.2.2 If vents or drains are specified to be in the tubesheet, installation shall be in accordance with applicable details in PIP VEFV1100.
4.3.3 Exchanger Supports

4.3.3.1 Exchanger supports shall be in accordance with PIP VECV1001, Section 4.2.12.

4.3.3.2 Stacked exchangers shall have the lower shell(s) designed to withstand the superimposed load of the upper exchanger(s) filled with water or operating fluid, whichever is greater, without distorting the shell in a manner that can cause binding of tube bundle(s).

4.3.3.3 If two or more exchangers are stacked, a 1/2-inch (13 mm) shimming allowance shall be provided between intermediate supports.

4.3.3.4 The lower fixed support of stacked exchangers shall be designed for the full bundle-pulling load (i.e., 2 times the bundle weight unless otherwise specified) for removal of any upper bundle.

4.3.3.5 Effects of differential thermal and pressure expansion between exchangers shall be considered for the design of exchanger supports.

4.3.4 Shells and Bonnets

4.3.4.1 For shell and bonnet sections NPS 24 (DN 600) and less, commercially produced NPS pipe should be used.

4.3.4.2 If specifying NPS pipe, pipe manufacturer’s tolerance for inside diameters shall be considered if internals (e.g., minimum tube counts) are critical.

4.3.5 Exchanger Covers

4.3.5.1 Except for kettle type exchangers, TEMA Type T exchangers shall have removable shell covers.

4.3.5.2 Mitered 90° reducing elbows for thermosyphon reboiler outlet heads shall be in accordance with the following requirements:
   a. Three or more changes in direction at the inside and outside contour shall be provided.
   b. Cyclic loading shall not be a governing design requirement.
   c. For gradual flow transition, meridian (i.e., change of direction) angles between adjacent sections shall be approximately equal.
   d. The general contours shall be similar to those of commercial forged reducing elbows.

4.3.6 Tubes

4.3.6.1 General Information

   1. The following tube properties shall be specified on the Purchaser’s PIP VEDST003-D Data Sheet:
      a. Number
      b. Diameter
      c. Wall thickness
d. Pitch  
e. Layout  
f. Length  
g. Welded or seamless  
h. Corrosion allowance, if applicable  
   Comment: Typically, corrosion allowance is not applicable to tubes.  
i. Tube enhancements and turbulence promoters, if applicable (see Section 4.3.6.5)  
j. U-tube bend diameters  

2. Tubes shall be either welded or seamless type.  
3. Circumferentially welded tubes shall not be permitted.

### 4.3.6.2 Recommended Tube Diameter

For recommended tube diameters for dirty and clean service types see Table 1.

<table>
<thead>
<tr>
<th>Service</th>
<th>Tube Diameter (OD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy Tube Side Fouling (Dirty Service) (Note 1)</td>
<td>≥ 1</td>
</tr>
<tr>
<td>Light Tube Side Fouling (Clean Service) (Note 2)</td>
<td>≥ ¾</td>
</tr>
</tbody>
</table>

Notes:  
1. Greater than or equal to 0.002 hr-ft²-°F/BTU (0.0004 hr-m²-°C/kcal)  
2. Less than 0.002 hr-ft²-°F/BTU (0.0004 hr-m²-°C/kcal)

### 4.3.6.3 Recommended Tube Wall Thickness

For recommended tube wall thicknesses for various tubing materials of construction see Table 2.

<table>
<thead>
<tr>
<th>Tube Material</th>
<th>Tube Wall Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon steel, low-alloy steel, aluminum, and aluminum alloys</td>
<td>14 minimum</td>
</tr>
<tr>
<td>Copper and copper alloys</td>
<td>16 minimum</td>
</tr>
<tr>
<td>High-alloy steel and other non-ferrous materials</td>
<td>16 average</td>
</tr>
<tr>
<td>Titanium</td>
<td>20 average</td>
</tr>
</tbody>
</table>

Note:  
BWG = Birmingham Wire Gauge
4.3.6.4 Length

If practical, commonly used tube lengths shall be specified.

4.3.6.5 Enhanced Surface Tubes and Turbulence Promoters

1. Enhanced surface tubes and turbulence promoters may be specified as a design alternate.

2. The use of enhanced surface tubes or tube inserts shall be approved by User.
   
   Comment: Enhancements may be effective in one process, but not in another. Enhanced surfaces are available in many forms (e.g., low fin, sintered metal, oval or deformed tubes, or tubes with longitudinal fins). Inserts are used to promote turbulence. Spiral inserts can reduce fouling buildup.

3. Low fin tubes may be used under the following conditions:
   a. Deposition of solid matter on the tube surface from the shell side stream cannot occur
   b. Tube side inlet temperatures are well above the shell side stream pour-point temperature
   c. Surface tension cannot “hold” the condensate in the fins
   d. Tube external corrosion cannot occur

4. If enhanced surface tubes or turbulence promoters are required, they shall be specified in the notes section of the Purchaser’s PIP VEDST003-D Data Sheet.

4.3.6.6 U-Tube Bends

The minimum mean bend diameter of U-tubes shall not be less than 3 times the nominal tube outside diameter.

4.3.7 Tubesheets

4.3.7.1 Tubesheets shall be designed for full design pressure on either side, with atmospheric pressure or specified vacuum on the other side.

4.3.7.2 Differential pressure design may only be used if approved by User.

4.3.7.3 Tubesheets for U-tube, fixed tubesheet and floating tubesheet heat exchangers shall be designed in accordance with Code, Part UHX-12, 13, and 14 {4.18.7, 4.18.8, and 4.18.9}.

4.3.7.4 Typically, tubesheets welded to a carbon steel shell or channel shall be of carbon steel or clad carbon steel.

4.3.7.5 If in accordance with either of the following conditions, solid alloy tubesheets may be welded to a carbon steel shell or channel:
   a. Thermal coefficients of expansion do not vary more than 15% from the tubesheet to the shell or channel over the operating temperature range.
b. If a stress analysis for the joint between the tubesheet and the shell or channel is specified on Purchaser’s PIP VEDST003-D Data Sheet, performed by Manufacturer, and approved by User

4.3.7.6 A solid alloy tubesheet may be welded to a short cylindrical section of the same alloy material to be welded to a carbon steel shell or channel. A stress analysis of the junction of the alloy and carbon steel cylindrical section shall be performed and submitted to User for approval.

4.3.7.7 In addition to TEMA requirements for tubesheet cladding, adequate cladding thickness under pass partition and gasket grooves shall be provided.

4.3.7.8 Loose liners and plug-welded liners shall not be permitted.

4.3.7.9 Confining gasket grooves shall be provided for all exchangers with gasketed pass partition joints.

4.3.7.10 For either shell side or tube side, nozzles shall not be located closer to an integrally attached tubesheet than shown in detail PIP VEFV1132.

4.3.8 Tube-to-Tubesheet Joints

4.3.8.1 Expanded Joints

1. Expanded joints shall have at least two grooves.
2. Grooves shall not be located in clad material.

4.3.8.2 Seal-Welded Joints

1. If tube-to-tubesheet leakage can be detrimental to the process, seal-welding of expanded tube joints shall be specified.
2. If transient operations can occur, seal-welding of expanded tube joints should be considered.
3. As a minimum, integrally clad tubesheets shall be seal-welded with expanded tube joints.

4.3.8.3 Strength-Welded Joints

Strength-welded tube-to-tubesheet joints shall be specified for either of the following conditions:

a. Expanded joints cannot carry the expected tube load

b. The residual interface pressure because of expansion (e.g., tube rolling or hydraulic expansion) can be lessened because of operating conditions

Comment: The loss of residual interface pressure can occur in high temperature applications or if significant differential thermal expansion occurs between the tube and the tubesheet.

4.3.9 Cross-Baffles and Support Plates

4.3.9.1 Cross-baffle metallurgy and thickness shall be selected considering the corrosivity of the shell side fluids and the intended design life.
4.3.9.2 Cross-baffles not susceptible to corrosion shall have a thickness of the greater of the following:
   a. Thickness specified by TEMA
   b. 1/8 inch (3 mm)

4.3.9.3 Cross-baffles susceptible to corrosion shall have a thickness of the greatest of the following:
   a. Minimum thickness specified by TEMA
   b. Two times the applicable corrosion allowance
   c. 3/16 inch (5 mm)

4.3.9.4 The end-baffle spaces shall be equal to or greater than the cross-baffle space.

4.3.9.5 A support plate placed before a floating tube sheet shall have a central opening with equal area to that of a segmental baffle.

4.3.9.6 Thickness of a support plate shall be the greater of the following:
   a. 5/8 inch (16 mm)
   b. Segmental baffle thickness plus two times the applicable corrosion allowance

4.3.10 Expansion Joints

4.3.10.1 Shell expansion joints shall be of the “thick wall” flanged and flued type or flanged only type (see Code, Appendix 5 {4.18.12}).

4.3.10.2 “Thin wall” bellows type expansion joints shall only be used if all of the following apply:
   a. Approved by User
   b. Design in accordance with Code, Appendix 26 {4.19}
   c. Welding stubs are of the same material as the shell

4.3.11 Vapor Belts

4.3.11.1 Use of vapor belts shall be specified on the Purchaser’s PIP VEDST003-D Data Sheet.

4.3.11.2 Vapor belt flexibility shall be considered in the design of exchanger shell, tubes, and tubesheets.

4.3.11.3 Vapor belts may be used as expansion joints provided all requirements of Section 4.3.10 are met.

4.3.12 Skid Bars

4.3.12.1 Exchangers with removable tube bundles weighing 20,000 pounds (9070 Kg) or greater shall have a minimum of two skid bars.

4.3.12.2 Skid bars shall have a thickness equal to or greater than the following:
   a. Cross-baffle thickness
b. ½ inch (12 mm) minimum

4.3.12.3 Skid bars shall have a 1-½ inch (38 mm) minimum height flat bar.
4.3.12.4 Skid bars shall be located 30° or less from the vertical centerline.
4.3.12.5 The skid bars shall extend from the stationary tubesheet to the following:
   a. For TEMA Types S and T exchangers, floating head support plate
   b. For TEMA Types P, U, and W exchangers, end baffle
4.3.12.6 Requirements for rolling elements for removal of very large exchanger bundles shall be specified on Purchaser’s PIP VEDST003-D Data Sheet.

4.3.13 Impingement Protection

4.3.13.1 Perforated or slotted impingement plates shall not be permitted.
4.3.13.2 If applicable, impingement protection type shall be specified on Purchaser’s PIP VEDST003-D Data Sheet.

4.3.14 Miscellaneous

4.3.14.1 All TEMA Type S and T exchangers (i.e., with removable shell cover) shall have a floating head support plate located 4 to 6 inches (100 to 150 mm) from the inside face of the floating tubesheet.
4.3.14.2 For orders of multiple exchangers of the same TEMA size and material, either stacked or parallel, the exchangers shall have interchangeable components to the maximum extent possible.

4.3.15 Kettle Type Exchangers

4.3.15.1 If a weir plate is required for a kettle type exchanger, the plate shall be of sufficient height to flood the top row of tubes with a minimum of 2 inches (50 mm) of process fluid during normal operation.
4.3.15.2 Drains shall be provided on both sides of the weir, either on the exchanger itself or the connected piping.
4.3.15.3 All kettle type exchangers shall be provided with either of the following configurations:
   a. A 3 inch (75 mm) minimum length cylindrical section (including flanged hub, if provided) between the shell flanges and conical transitions
   b. Other alternatives for cone-to-flange fit-up and bolting clearance

4.4 Thermal Design

4.4.1 General

4.4.1.1 Thermal design of shell-and-tube heat exchangers shall consider safety, operation, maintenance, and initial cost aspects of the intended service.
4.4.1.2 Each heat exchanger unit shall be independently designed.
4.4.1.3 The thermal design method used shall be approved by User.
4.4.2 Fouling Factors Selection

4.4.2.1 Typically, fouling factors shall be determined from previous experience or similar service.

4.4.2.2 If previous experience or similar service is not available, the fouling factors for each fluid shall be selected from TEMA.

4.4.2.3 To distinguish between clean and dirty, service may be defined as dirty if the fouling factor is equal to or greater than 0.002 hr-ft²-°F/BTU (0.0004 hr-m²-°C/kcal). A lower fouling factor implies a clean service.

4.4.2.4 Arbitrarily high fouling factors shall not be used to provide thermal overdesign or to compensate for uncertainties in thermal properties or process design.

4.4.2.5 High heat transfer coefficients shall not be expected if high fouling factors are used; low heat transfer coefficients shall not be expected if low fouling factors are used.

4.4.2.6 The percentage of surface area added as a result of the fouling factor shall be approved by User.

4.4.2.7 The clean exchanger performance shall be reviewed by User.

Comment: The service overall heat transfer coefficient divided by the clean overall heat transfer coefficient determines the fraction of surface required for the heat exchanger to meet the process requirements when the exchanger is clean. The balance of the surface exists for fouling. Excessive surface available for fouling can be expensive, promote fouling, and make the exchanger difficult to control when it is clean.

4.4.3 Fluid Side Selection

4.4.3.1 For selection of fluid side for an exchanger, maintenance, operation, size, and cost shall be considered.

4.4.3.2 Conditions favoring shell side fluid placement include the following:
   a. More viscous services
   b. Low available pressure drop
   c. Clean service

4.4.3.3 Conditions favoring tube side fluid placement include the following:
   a. Cooling water service
   b. Slurry service
   c. High-pressure service
   d. Higher fouling service
   e. Service requiring more expensive materials
4.4.4 Thermal Performance

4.4.4.1 Condensing Heat Transfer

1. For accurate condenser design, the temperature difference shall be calculated incrementally.

   Comment: The temperature and heat transfer of the condensing vapor mixtures varies with the fraction condensed. Even with pure components, the condensing temperature varies if there is significant pressure drop.

2. The effect of delta P on delta T shall be checked, especially if the overall delta T is small.

3. For rough calculations, a straight line temperature may be used for the condensing zone.

4. For final design, the results shall always be checked using stepwise increments.

5. Special considerations are required for the following conditions:
   a. Vapor entering a condenser is superheated (i.e., temperature above the dew point)
   b. Condensate from a condenser is subcooled (i.e., temperature below the bubble point)

6. If the temperature of the heat transfer surface (i.e., tube wall temperature) encountered is less than the dew point of the vapor, the vapor begins to condense on contact and a wet wall condition occurs. In such cases, a condensing heat transfer coefficient shall be used, as in the case of saturated vapor, and the Mean Temperature Difference (MTD) shall be based on the dew point temperature rather than the superheated vapor temperature.

7. If the tube wall temperature is greater than the dew point of the vapor, a dry wall condition occurs. In such cases, the single phase gas heat transfer coefficient shall be used and the actual vapor temperature shall be used to calculate the MTD for the increment of the exchanger at dry wall conditions.

8. Significant subcooling duty shall be provided in a separate liquid cooler.

   Comment: Some subcooling of condensate usually occurs in total condensers. Condensers can sometimes be designed to accommodate subcooling by flooding a portion of the shell with condensate. However, the accuracy of predicting subcooling performance is low because the true liquid level and subcooling MTD are almost impossible to determine.

4.4.4.2 Water Cooled Services (Cooling Water on Tube Side)

1. An optimal velocity shall be selected with considerations given to installed and maintenance costs.
Comment: If the cooling water is on the tube side, water velocity significantly affects the fouling rate, erosion, corrosion, and resulting maintenance of installed equipment.

2. Tables 3, 4, and 5 provide values for minimum and maximum velocities and maximum tube wall temperature that shall be used if site-specific data is not available.

Comment: Blanks in Tables 3 and 4 indicate that the listed material is generally not specified for the application.

### Table 3. Minimum Velocity Ft/sec (m/sec)

<table>
<thead>
<tr>
<th>Material</th>
<th>Evaporative Riding Tower (See Note)</th>
<th>Closed Loop</th>
<th>Brackish</th>
<th>Raw Surface</th>
<th>Seawater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferrous</td>
<td>5 (1.5)</td>
<td>3 (0.9)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Nonferrous</td>
<td>5 (1.5)</td>
<td>3 (0.9)</td>
<td>4 (1.2)</td>
<td>5 (1.5)</td>
<td>5 (1.5)</td>
</tr>
</tbody>
</table>

Note: Lower minimum velocities may be necessary in some cases because of hydraulic limitations. Consideration shall be given to the water quality and higher fouling factors for these cases.

### Table 4. Maximum Velocity Ft/sec (m/sec)

<table>
<thead>
<tr>
<th>Material</th>
<th>Evaporative Riding Tower</th>
<th>Closed Loop</th>
<th>Brackish</th>
<th>Raw Surface</th>
<th>Seawater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferrous</td>
<td>10 (3)</td>
<td>16 (4.9)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Admiralty</td>
<td>8 (2.4)</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Al-Brass</td>
<td>8 (2.4)</td>
<td>---</td>
<td>6 (1.8)</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Cupro-Nickel</td>
<td>12 (3.7)</td>
<td>---</td>
<td>7 (2.1)</td>
<td>7 (2.1)</td>
<td>7 (2.1)</td>
</tr>
<tr>
<td>Aust. SS</td>
<td>---</td>
<td>16 (4.9)</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Monel</td>
<td>16 (4.9)</td>
<td>16 (4.9)</td>
<td>14 (4.3)</td>
<td>14 (4.3)</td>
<td>14 (4.3)</td>
</tr>
<tr>
<td>Titanium</td>
<td>16 (4.9)</td>
<td>16 (4.9)</td>
<td>16 (4.9)</td>
<td>16 (4.9)</td>
<td>16 (4.9)</td>
</tr>
</tbody>
</table>

### Table 5. Maximum Contacted Tube Wall Surface Temperature, °F (°C) (See Note)

<table>
<thead>
<tr>
<th>Material</th>
<th>Evaporative Riding Tower</th>
<th>Closed Loop</th>
<th>Brackish</th>
<th>Raw Surface</th>
<th>Seawater</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Material</td>
<td>140 (60)</td>
<td>No Limit</td>
<td>140 (60)</td>
<td>120 (49)</td>
<td>140 (60)</td>
</tr>
</tbody>
</table>

Note: If there is no fouling on the hot side, the Maximum Temperature applies to the metal surface beneath any fouling layer on the waterside.
4.5 **Hydraulic Performance**

4.5.1 The requirements for thermal design described in Section 4.4 also apply to the hydraulic design.

4.5.2 Pressure drop design factors shall be approved by User.

4.5.3 Pressure drop considerations shall include the following:
   a. Mill tolerance of tubes
   b. Fouling build up on tube side and shell side
   c. Piping between exchangers in series
   d. Piping for thermosyphon reboilers

4.6 **Vibration**

4.6.1 Flow-induced tube vibration shall be considered.

4.6.2 The method of vibration analysis shall be approved by User.

4.6.3 The vibration analysis shall consider, as a minimum, the following conditions:
   a. Vortex shedding
   b. Fluid elastic instability
   c. Turbulence excitation (i.e., buffeting)
   d. Acoustic resonance

4.6.4 The natural frequency (i.e., harmonics) of the tubes shall not be within 20% of the predicted flow vibration frequency produced by any excitation mode.

4.6.5 For floating tube sheet bundles, the flow induced vibration evaluation shall not take credit for the opening in a support plate. Spacing between the last segmental baffle and support plate shall be considered as outlet spacing.