

# DEP SPECIFICATION

## SHELL AND TUBE HEAT EXCHANGERS; SELECTION AND APPLICATION

DEP 31.21.01.12-Gen.

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DESIGN AND ENGINEERING PRACTICE

DEM1



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## 1. INTRODUCTION

### 1.1 SCOPE

This DEP specifies requirements and gives recommendations for thermal and mechanical design of shell-and-tube heat exchangers for which API STD 660 and DEP 31.21.01.30-Gen. are applied.

This DEP is not intended to be used for the following heat exchangers:

- small shell-and-tube heat exchangers (i.e., having a bare tube surface area of less than 0.5 m<sup>2</sup> (5.4 ft<sup>2</sup>);
- pressurized water-cooled (or glycol-cooled) seal-oil coolers;
- lube-oil coolers;
- jacket water coolers for rotating equipment;
- vacuum-operated steam surface condensers;
- feed water heaters;
- hairpin heat exchangers;
- alkylation contactor bundles of proprietary design.

This DEP specifies the thermal and mechanical design considerations for shell and tube heat exchangers to assist the design team/designer of either the Principal or the Contractor. It provides specifications to direct selection/design of cost effective heat exchangers that are consistent with the service conditions, intended design life, and criticality of the application.

This DEP is used in conjunction with the thermal design, data/requisition sheet (DEP 31.21.00.93-Gen.).

This DEP is premised on the user being familiar with DEP 31.21.01.30-Gen. and API STD 660, which are primarily intended for use by the Manufacturer/Supplier.

This DEP covers the general specification requirements of the shell and tube heat exchanger data/requisition sheet with design notes and the general information typically required for a bid requisition. This DEP, therefore, is not intended for use by shell and tube heat exchanger Manufacturers/Suppliers.

This DEP contains mandatory requirements to mitigate process safety risks in accordance with Design Engineering Manual (DEM) 1 – Application of Technical Standards.

This is a revision of the DEP of the same number dated February 2014; see (1.5) regarding the changes.

### 1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by Shell GSI, the distribution of this DEP is confined to Shell companies and, where necessary, to Contractors and Manufacturers/Suppliers nominated by them. Any authorized access to DEPs does not for that reason constitute an authorization to any documents, data or information to which the DEPs may refer.

This DEP is intended for use in facilities related to oil and gas production, gas handling, oil refining, chemical processing, gasification, distribution and supply/marketing. This DEP may also be applied in other similar facilities.

When DEPs are applied, a Management of Change (MOC) process shall be implemented; this is of particular importance when existing facilities are to be modified.

If national and/or local regulations exist in which some of the requirements could be more stringent than in this DEP, the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be

acceptable with regards to the safety, environmental, economic and legal aspects. In all cases, the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned, the objective being to obtain agreement to follow this DEP as closely as possible.

### 1.3 DEFINITIONS

#### 1.3.1 General definitions

The **Contractor** is the party that carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project or operation of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party that manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party that initiates the project and ultimately pays for it. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The capitalised term **SHALL [PS]** indicates a process safety requirement.

The word **should** indicates a recommendation.

The word **may** indicates a permitted option.

#### 1.3.2 Specific definitions

| Term                           | Definition                                                                                                                                                                                                                              |
|--------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Data/Requisition Sheet</b>  | Data/requisition sheet DEP 31.21.00.93-Gen. or Principal-approved equivalent, which is used in conjunction with this DEP.                                                                                                               |
| <b>Hydrogen Service</b>        | Any service in which the hydrogen partial pressure is greater than 700 kPa absolute (100 psia) at any temperature                                                                                                                       |
| <b>Oxygen Service</b>          | A service with an oxygen content greater than 21 vol% with the balance being inert.                                                                                                                                                     |
| <b>Very toxic (substances)</b> | Refer to DEP 01.00.01.30-Gen. for additional details concerning the definitions of "very toxic - acute", "very toxic - chronic", and "very toxic - environment". For this DEP, the term "very toxic" is meant to cover all three types. |

#### 1.3.3 Abbreviations

| Term        | Definition                                                         |
|-------------|--------------------------------------------------------------------|
| <b>BDEP</b> | Basic Design Engineering Package                                   |
| <b>CFD</b>  | Computational Fluid Dynamics                                       |
| <b>FEA</b>  | Finite Element Analysis                                            |
| <b>HIC</b>  | Hydrogen Induced Cracking                                          |
| <b>HTFS</b> | Heat Transfer and Fluid Flow Services software, new name is Aspen+ |

| Term  | Definition                                    |
|-------|-----------------------------------------------|
| HTRI  | Heat Transfer Research Inc.                   |
| ID    | Inside diameter                               |
| MTD   | Mean temperature difference                   |
| NTIW  | No tubes-in-window                            |
| OD    | Outside Diameter                              |
| SCOT  | Shell Claus offgas treatment                  |
| SOHIC | Stress-Oriented Hydrogen-Induced Cracking     |
| SSC   | Sulphide Stress Cracking                      |
| STHE  | Shell and tube heat exchanger                 |
| TEMA  | Tubular Exchangers Manufacturer's Association |
| WHE   | Waste Heat Exchanger                          |

#### 1.4 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section or clause number is shown in brackets ( ). Other documents referenced by this DEP are listed in (5).

#### 1.5 SUMMARY OF CHANGES

This DEP is a revision of the DEP of the same number dated February 2014. The following are the main, non-editorial changes.

| Section/Clause | Change                                                                                                                                                                                                                                 |
|----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| All            | This revision represents a significant change and greatly simplifies the application of the DEP through simplification, along with a reduction in the number of shall statements, which were challenged based on a risk/benefit ratio. |
| All            | 3 SHALL [PS] statements remain in (2.2), all others throughout the entire Specification were reviewed and deleted as no longer being justified or replaced by requirements elsewhere.                                                  |

## 1.6 COMMENTS ON THIS DEP

Comments on this DEP may be submitted to the Administrator using one of the following options:

|                                                                      |                                                                                                                                                                                                                                                                   |
|----------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Shell DEPs Online</b><br>(Users with access to Shell DEPs Online) | Enter the Shell DEPs Online system at <a href="https://www.shelldeps.com">https://www.shelldeps.com</a><br><br>Select a DEP and then go to the details screen for that DEP.<br><br>Click on the "Give feedback" link, fill in the online form and submit.         |
| <b>DEP Feedback System</b><br>(Users with access to Shell Wide Web)  | Enter comments directly in the DEP Feedback System which is accessible from the Technical Standards Portal <a href="http://www.shell.com/standards">http://www.shell.com/standards</a> .<br><br>Select "Submit DEP Feedback", fill in the online form and submit. |
| <b>DEP Standard Form</b><br>(other users)                            | Use DEP Standard Form 00.00.05.80-Gen. to record feedback and email the form to the Administrator at <a href="mailto:standards@shell.com">standards@shell.com</a> .                                                                                               |

Feedback that has been registered in the DEP Feedback System by using one of the above options will be reviewed by the DEP Custodian for potential improvements to the DEP.

## 1.7 DUAL UNITS

This DEP contains both the International System (SI) units, as well as the corresponding US Customary (USC) units, which are given following the SI units in brackets. When agreed by the Principal, the indicated USC values/units may be used.

## 1.8 NON NORMATIVE TEXT (COMMENTARY)

Text shown in italic style in this DEP indicates text that is non-normative and is provided as explanation or background information only.

*Non-normative text is normally indented slightly to the right of the relevant DEP clause.*

## 2. THERMAL AND HYDRAULIC DESIGN AND SPECIFICATION

### 2.1 INTRODUCTION

*This document is intended primarily for use by the Principal and Contractor to complete the thermal design, data/requisition sheet (DEP 31.21.00.93-Gen., or equivalent), and supplementary technical requirements necessary for a complete set of design, materials, fabrication, inspection and testing instructions to the Manufacturer/Supplier.*

1. The Contractor shall provide the complete process, thermal and mechanical design specification for the application.
  - a. When approved by the Principal, the thermal design may be delegated to the Manufacturer/Supplier.
2. Thermal design of shell and tube exchangers for auxiliary services used in packaged for rotating equipment (e.g., seal oil, lube oil coolers) may be performed by the Manufacturer/Supplier.
  - a. In these cases, the Contractor shall validate the Manufacturer/Supplier's proposed thermal design.
3. A data/requisition sheet (DEP 31.21.00.93-Gen. or the Contractor's equivalent where approved by the Principal) shall be completed.
4. When providing specifications for shell-and-tube heat exchangers and filling in data/requisition sheets, the items in API STD 660 marked with a bullet (●) shall be provided by the Contractor.
  - a. Standard Form DEP 31.21.01.83-Gen. may be utilized for this purpose.

### 2.2 PROCESS SPECIFICATION

1. Stream physical properties and data should be provided to allow for the thermal and hydraulic design of the exchanger to be completed.
  - a. Transport properties for well-known components such as air, steam or cooling water do not need to be specified.
2. For single phase applications, transport properties (viscosity, density, thermal conductivity, specific heat) should be provided at the inlet and exit conditions.
  - a. For cooling of liquid streams with a viscosity greater than 10 cP at the specified outlet temperature, a viscosity curve with intermediate temperatures should be provided, spanning from the hot side inlet temperature down to a temperature equal to the cold side fluid inlet temperature, so that the viscous boundary layer at the tube wall can be properly characterized.
3. For condensing and boiling streams, the transport properties and heat release data should be determined under the assumption of thermodynamic equilibrium and provided for each phase at the inlet, outlet, and several intermediate temperature points based on equal enthalpy intervals.
4. For condensing and boiling streams, the following data should be provided:
  - a. The transport properties based on the total composition of each phase including water, air and steam when these components are part of a homogeneous phase.
  - b. Liquid properties at the dew point and vapour properties at the bubble point when such points occur within the heat exchanger.
  - c. If water is present, then the water dew point at the operating pressure.
  - d. Heat release from inlet (or total stream enthalpy).
  - e. The weight fraction vapour, along with the percent (by weight) of any second liquid phase (if present).

- f. The vapour molecular weight.
5. If the liquid formed during condensation has immiscible components, then liquid properties should be specified completely for each individual liquid phase and for the combined 'mixed phase' liquid.
6. Where multiple liquid phases exist which may form an emulsion, the heat exchanger designer and the process engineering specialist should agree on the property data to be provided.

*The apparent or emulsion viscosity to be used in the design of the heat exchanger can have a significant effect on the equipment sizing.*

7. Where process fluids which exhibit non-Newtonian behaviour exist, the heat exchanger designer and the process engineering specialist should agree on the property data to be provided.
8. If the design of the heat exchanger is such that liquid/vapour separation occurs to an extent sufficient to alter vapour-liquid equilibrium implicit in (2.2, Item 3), additional heat release profiles and vapour/liquid transport properties based on a differential condensation method should be provided.

*Differential condensation curves consider that the liquid and vapour phases separate as they are formed and do not remain in thermodynamic equilibrium.*

9. For boiling streams, the following additional property data should be provided:
- surface tension of the liquid phase;
  - boiling range (i.e., dew point temperature minus bubble point temperature at constant pressure);
  - the true critical pressure and critical temperature of the liquid, and the number of components (present in at least 5 % by mole).

*The true critical pressure can be estimated by increasing the pressure of a multi-component mixture until the dew point and bubble point are equal.*

*The use of the mole fraction average critical pressure, or pseudo-critical pressure, can lead to inaccuracies when used to calculate the heat transfer coefficient or critical heat flux.*

10. For condensing streams, the following additional property data should be provided:
- surface tension of the liquid phase;
  - the mole fraction of non-condensable components at the exchanger's inlet conditions when these are present in an amount greater to or equal to 5 %.
11. For condensing or boiling (non-thermosiphon applications) at operating pressures between ambient pressure and 2,100 kPag (300 psig), at least two isobaric heat curves should be included on the data sheet and in the thermal design simulation, with one at the inlet pressure and the other at the inlet pressure less the allowable pressure drop.
12. For condensing or boiling (non-thermosiphon applications) operating under vacuum conditions, a minimum of three isobaric heat curves should be provided at the inlet pressure, expected outlet pressure, and at the average pressure between the inlet and outlet.
13. For condensing or boiling (non-thermosiphon applications) at operating pressures greater than 2,100 kPag (300 psig), a single heat release curve may be provided with the pressure varying linearly from the inlet to outlet condition, assuming that all of the allowable pressure drop will be utilized.

14. For thermosiphon reboilers, the following isobaric heat curves should be provided for the boiling fluid:
- the column sump pressure;
  - the column sump pressure plus 3.75 m (12 ft) of liquid head;
  - at the column sump pressure plus 7.5 m (24 ft) of liquid head.
  - any additional heating curves at other isobaric pressures determined to be necessary for the design of the exchanger.

*Isobaric heat curves are provided in order to estimate the onset of boiling for the feed to the reboiler, which is sub-cooled due to the static head introduced by the elevation difference between the column sump and the reboiler.*

*The heat exchanger designer determines if additional curves are needed and obtains the additional information from the process engineer accordingly.*

15. Where actual hydraulic information is available (static head and piping arrangements), the process curves should be provided at the following pressures:
- at the sump pressure,
  - a pressure equal to the actual head
  - a pressure midway between the sump and actual head value.
16. When present, the following data should be provided for the solids in the stream:
- nature (e.g., silt, sand, fines, and catalyst fines),
  - size (e.g., microns), size distribution (if known);
  - shape (if known);
  - quantity (in wt% or ppm) .

*The presence of solids is particularly important for design of pressure equipment in upstream environments (e.g., production coolers, tailings, slurry services in mining, froth treatment facilities) and catalytic cracking units to prevent plugging or erosion.*

17. If the heat exchanger designer considers the process data provided to be insufficient for design purposes, additional data should be requested from the process engineering specialist.
18. The Contractor SHALL [PS] indicate if the service is in sour or wet H<sub>2</sub>S service and clearly identify the sulphide stress cracking (SSC), hydrogen blistering, hydrogen induced cracking (HIC), stress-oriented hydrogen induced cracking (SOHIC), or carbonate cracking severity ratings on the data/requisition sheet.
- Refer to DEP 30.10.02.17-Gen. or DEP 39.01.10.12-Gen., as applicable for information on sour or wet H<sub>2</sub>S service designations.
19. Any applicable limitations with respect to the tube wall or bulk fluid temperatures should be provided.
- Such limitations include a thermal degradation/coking point, the freezing point, the pour point, the wax point, the dew point (if condensation may result in increased corrosion), the hydrate formation point, or any other temperature, which can create operating difficulties for a heat exchanger.*
20. The Contractor SHALL [PS] indicate any exchangers subject to hydrogen service, along with the hydrogen partial pressure, on the data/requisition sheet.
21. The Contractor SHALL [PS] indicate any exchangers subject to very toxic service on the data/requisition sheet.
22. The Contractor shall indicate if post-weld heat treatment is required for process service reasons on the data/requisition sheet.

23. Data sheets and curve-specified data shall represent the design conditions.
- a. The heat duty shall be consistent with the flows and temperatures specified.
24. All expected operating scenarios/conditions, including turndown, predictable upset conditions, or alternate modes of operation (e.g., steam-out) should be identified on the data/requisition sheets when they are expected to lead to any of the following:
- a. impose additional heat duty requirements on the exchanger design;
  - b. require additional heat transfer surface area be provided;
  - c. result in a higher stream pressure drop;
  - d. result in mechanical design conditions (e.g. mean shell and tube metal temperatures) which may determine the need for an expansion joint.

25. An alternate operating case should not be dismissed from analytical review simply because it is a lower heat duty case.

*Indicating all modes of operation is needed to ensure an adequate mechanical design, including the specification of expansion joint requirements.*

26. The fouling resistances or design margins to be applied shall be subject to approval by the Principal and determined from one of the following:
- a. DEP 20.21.00.31-Gen.;
  - b. facility experience for a specific service;
  - c. project specific information;
  - d. licensor requirements.

*When no other data or experience is available, TEMA recommended values for the most similar fluid may be considered.*

27. Where cooling water systems are such that winter operation water temperatures could be 15 °C (30 °F) or more colder than the design water temperature (e.g., once-through cooling water systems), the lower water temperature shall be identified on the data/requisition sheet (i.e., through specification of separate summer and winter cases).
- a. The exchanger shall be evaluated to ensure that operating or control problems will not exist during winter mode of operation (e.g., low velocity and high fouling potential due to excessive flow through a control bypass line).
28. If excess flow, duty or heat exchanger capacity is required, the required temperatures, flows and duty for the condition shall be specified as a unique process design case to ensure the heat exchanger is designed appropriately.
- a. Heat exchangers should not be specified to have or require "excess surface" for a process margin.
29. When fluid by-pass is used as the means for process control of a heat exchanger, the design condition should consider a minimum of 10 % of the heat and material balance flow rate to be bypassed for the bypassed stream.
- a. The by-pass should be applied to the side of the exchanger which exhibits the lower fouling tendency, wherever possible.

*Bypassing high fouling fluids for temperature control, leads to lower velocities and can result in increased fouling rates. There may be some process services, however, where it is necessary to do so (e.g., FCC bottoms slurry or delayed coker main bottoms) in order to have sufficient temperature control.*

## 2.3 GENERAL THERMAL DESIGN

1. The validation of thermal and hydraulic design should be based on the design procedures and computer programs published by Heat Transfer Research Inc. (HTRI) or Aspen Exchanger Design and Rating software.
  - a. Alternate calculation methods may be used only after the approval of the Principal.
2. Discrepancies in the performance prediction results between different design methods shall be referred to the Principal for resolution.
3. The applicable versions of computer programs used for thermal design shall be subject to the approval of the Principal.
4. Heat exchanger thermal rating files (including the native electronic input files) reflecting the as-built design should be turned over to the Principal at the end of the project.
5. Heat exchangers should be provided with effective surface areas between 100 % and 105 % of the required surface area for the design condition.

*The design condition might already require a process margin for example on flow rates and heat duty.*

*The Principal might specify an additional margin to be applied when necessary to account for uncertainties in the design methods applied.*

6. Heat exchangers should be of the horizontal configuration; however, the vertical arrangement may be considered for certain process requirements, or if there is limited space available.
7. Where a tube is specified to a minimum tube wall thickness, the tube wall thickness used for thermal and hydraulic calculation purposes shall be 1.1 times the minimum tube wall thickness.

*This ensures that the exchanger design more accurately reflects the furnished thickness supplied by the tube mill.*

8. The minimum velocities for single phase non-erosive liquid streams, excluding cooling water, should be as specified in Table 1.

**Table 1 Minimum velocities for single phase non-erosive liquid streams, excluding water**

| Fouling Characterization | Fouling Factor<br>$\text{m}^2\text{-K/W}$<br>( $\text{hr-ft}^2\text{-}^\circ\text{F/Btu}$ ) | Tube Side<br>Velocity; m/s<br>(ft/s) | Shell Side<br>Velocity; m/s<br>(ft/s) |
|--------------------------|---------------------------------------------------------------------------------------------|--------------------------------------|---------------------------------------|
| Very Low                 | $\leq 0.00009$ (0.0005)                                                                     | 1.0 (3.0)                            | 0.3 (1.0)                             |
| Low                      | $\leq 0.00026$ (0.0015)                                                                     | 1.0 (3.0)                            | 0.3 (1.0)                             |
| Medium                   | $\leq 0.00052$ (0.003)                                                                      | 1.5 (5.0)                            | 0.5 (1.6)                             |
| High                     | $\leq 0.0012$ (0.0068)                                                                      | 2.0 (6.5)                            | 0.6 (2.0)                             |
| Severe                   | $> 0.0012$ (0.0068)                                                                         | 2.2 (7.2)                            | 0.7 (2.3)                             |

9. The velocity should be maximized for the available pressure drop to provide the highest heat transfer coefficient and to reduce fouling tendency.
10. Refer to DEP 20.21.00.31-Gen. for cooling water velocity requirements.
11. The maximum in-tube velocity for lean Amine and Sulfinol streams shall be 2.4 m/s (8 ft/s).

12. The maximum in-tube velocity for rich Amine and Sulfinol streams shall be 1.5 m/s (5 ft/s) for carbon steel materials and 2.4 m/s (8 ft/s) for 316L stainless steel materials.
13. The maximum in-tube velocity for saturated vapours, two-phase fluids, and non-erosive liquids (excluding cooling water and Amine/Sulfinol streams) shall be such that the velocity head ( $\rho V^2$ ) in the tubes does not exceed 8,930 kg/m-s<sup>2</sup> (6,000 lb/ft-s<sup>2</sup>), unless otherwise approved by the Principal.

*V is the linear velocity in m/s (ft/s) and  $\rho$  is the fluid density in kg/m<sup>3</sup> (lb/ft<sup>3</sup>).*

- For two-phase fluids, the homogeneous velocity should be used.
- For non-erosive liquids, the maximum allowable velocity head shall be calculated using the equivalent maximum cooling water velocities as specified in DEP 20.21.00.31-Gen. for the different tube materials.

*The velocity limits are intended to prevent erosion of the tube inlets. Higher velocities might be accepted on a case by case basis or when tube ferrules, sleeves or similar devices are applied.*

*For dry non-erosive gasses, no specific tube velocity limits apply.*

- For erosive liquid streams, the Principal shall be consulted on minimum and maximum allowable velocities.
- The allowable pressure drop specified on the heat exchanger's process data sheet shall be applied as the maximum pressure drop in the exchanger's fouled condition.
  - For vapour and condensing streams, the allowable pressure drop should be determined based on process and pressure profile requirements.
  - For pumped liquid streams other than cooling water, the allowable pressure drop should be sufficient to achieve target design velocities in Table 1 to ensure optimum exchanger design, sizing and fouling minimization.
  - When the allowed pressure drops are insufficient to achieve the target velocities, the Principal shall be consulted.
  - Tables 2 and 3 provide an estimate of the pressure drops required for pumped liquids other than cooling water to achieve the target velocities and may be considered for initial hydraulic sizing.

**Table 2 Estimated allowable tube side pressure drop, kPa (psi)**

| Fouling Characterization | Fouling Factor<br>m <sup>2</sup> -K/W (hr-ft <sup>2</sup> -°F/Btu) | Liquid Viscosity at the Process Outlet Temperature <sup>1</sup> |            |                     |
|--------------------------|--------------------------------------------------------------------|-----------------------------------------------------------------|------------|---------------------|
|                          |                                                                    | ≤ 1 cP                                                          | ≤ 2 cP     | ≤ 5 cP <sup>2</sup> |
| Very Low                 | ≤ 0.00009 (0.0005)                                                 | 75 (11)                                                         | 110 (16)   | 165 (24)            |
| Low                      | ≤ 0.00026 (0.0015)                                                 | 75 (11)                                                         | 110 (16)   | 165 (24)            |
| Medium                   | ≤ 0.00052 (0.003)                                                  | 120 (17.5)                                                      | 150 (22)   | 210 (30.5)          |
| High                     | ≤ 0.0012 (0.0068)                                                  | 200 (30)                                                        | 225 (32.5) | 300 (43.5)          |
| Severe                   | > 0.0012 (0.0068)                                                  | 275 (40)                                                        | 315 (45)   | 350 (50)            |

**Table 3 Estimated allowable shell side pressure drop, kPa (psi)**

| Fouling Characterization                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Fouling Factor<br>$\text{m}^2\text{-K/W}$<br>( $\text{hr-ft}^2\text{-}^\circ\text{F/Btu}$ ) | Liquid Viscosity at the Process Outlet Temperature <sup>1</sup> |                      |                      |                        |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|-----------------------------------------------------------------|----------------------|----------------------|------------------------|
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                             | $\leq 5 \text{ cP}$                                             | $\leq 10 \text{ cP}$ | $\leq 25 \text{ cP}$ | $\leq 50 \text{ cP}^3$ |
| Very Low                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | $\leq 0.00009$ (0.0005)                                                                     | 35 (5)                                                          | 35 (5)               | 50 (7.5)             | 75 (11)                |
| Low                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | $\leq 0.00026$ (0.0015)                                                                     | 35 (5)                                                          | 50 (7.5)             | 75 (11)              | 100 (15)               |
| Medium                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | $\leq 0.00052$ (0.003)                                                                      | 50 (7.5)                                                        | 75 (11)              | 100 (15)             | 125 (18)               |
| High                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | $\leq 0.0012$ (0.0068)                                                                      | 75 (11)                                                         | 100 (15)             | 125 (18)             | 150 (22)               |
| Severe                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | $> 0.0012$ (0.0068)                                                                         | 100 (15)                                                        | 125 (18)             | 150 (22)             | 175 (25)               |
| <ol style="list-style-type: none"> <li>Values are estimated based on experience to allow the required minimum velocities to be achieved and to provide an optimized heat exchanger design. The values shown are per heat exchanger when multiple exchangers in series are used.</li> <li>For tube side fluids with liquid viscosity <math>&gt; 5 \text{ cP}</math>, consult the Principal's for further review. In such instance, the pressure drop should be sufficient to achieve the minimum velocity, and to avoid laminar and/or transitional flow where possible.</li> <li>For shell side fluids with liquid viscosity <math>&gt; 50 \text{ cP}</math>, consult the Principal. The pressure drop should be sufficient to achieve the minimum velocity, and to avoid laminar flow, where possible.</li> </ol> |                                                                                             |                                                                 |                      |                      |                        |

- Any opportunity to appreciably reduce the size or cost of the heat exchanger design by increasing the allowable pressure drop should be investigated to determine if the allowable pressure drop can be increased.
- Pressure drop in the fouled condition shall be estimated for use in hydraulic system calculations.

*Since the thickness and surface roughness of fouling deposits are not usually known, it is necessary to estimate the increase in pressure drop above a clean condition due to fouling, as it cannot be accurately calculated by simulation.*

- Except for cooling water, the pressure drop for the fouled condition shall be estimated by multiplying the calculated pressure drop for the clean condition by the appropriate factor from Table 4.

**Table 4 Hydraulic multipliers for fouling**

| Fouling Characterization | Fouling Factor<br>$\text{m}^2\text{-K/W}$ ( $\text{hr-ft}^2\text{-}^\circ\text{F/Btu}$ ) | Pressure Drop Multiplier |
|--------------------------|------------------------------------------------------------------------------------------|--------------------------|
| Very Low                 | $\leq 0.00009$ (0.0005)                                                                  | 1.1                      |
| Low                      | $\leq 0.00026$ (0.0015)                                                                  | 1.1                      |
| Medium                   | $\leq 0.00052$ (0.003)                                                                   | 1.2                      |
| High                     | $\leq 0.0012$ (0.0068)                                                                   | 1.3                      |
| Severe                   | $> 0.0012$ (0.0068)                                                                      | 1.4                      |

- For cooling water the following hydraulic multipliers shall be used:
  - 1.5 for cooling waters other than closed loop systems which utilize carbon steel tubes;

- b. 1.25 for cooling waters other than closed loop systems which utilize other tube materials;
  - c. 1.1 for closed loop cooling water systems regardless of tube materials.
19. When the thermal resistance due to fouling exceeds 50 % of the overall thermal resistance for the heat exchanger, the Principal should be consulted.
- Large amounts of excess area for fouling margins are discouraged as this can lead to poor exchanger design, control problems and an increase in fouling tendency. In these cases, it might be possible to decrease the fouling margin.*
20. For flow boiling services, geometries that allow the gross separation of liquid and vapour phases should not be used unless agreed by the Principal. See (2.7, Item 14) for more information.
- Gross separation of liquid and vapour phases can invalidate the assumptions of phase equilibrium and uniform flow distribution inherent in the thermal hydraulic performance modelling methods.*
- a. Additional analysis might be necessary and the Principal should be consulted for such situations.
21. Geometries that allow the gross separation of liquid and vapour phases should not be used for condensing services when all of the following conditions exist, unless a differential condensing curve has been applied:
- a. The condensing range exceeds 70 °C (125 °F).
  - b. The temperature approach at the process outlet is less than 8 °C (15 °F).
  - c. Greater than 22 °C (40 °F) of temperature range occurs in a gravity flow zone.
- For horizontal shell side condensers, liquid/vapour separation is generally not as critical as for boiling heat transfer.*
22. When the tube side fluid in a horizontal heat exchanger is either a multi-component condensing, boiling, or two-phase service, heat exchanger designs should utilize either a single tube pass or two-pass U-tube configurations.
- a. Two-pass straight tube designs may be used when it can be demonstrated by calculation that the flow regime in the pass turnaround and entry zones will be shear dominated for any operating condition and with the approval of the Principal.
23. The design heat flux in boiling applications should be less than 70 % of the critical heat flux calculated by HTRI.
24. Dry wall boiling (film boiling or mist flow) should be avoided if possible.
- The boiling heat transfer coefficient increases with the boiling side temperature difference (tube wall temperature minus boiling bulk temperature) up to a maximum heat flux, above which increasing the MTD or heating medium coefficient reduces the duty performed.*
25. The performance of the heat exchanger shall be evaluated for its clean condition operation, with consideration of the method of process control employed, under design and turndown conditions for operation problems (e.g., film boiling, increased fouling potential due to low flows, excessive tube wall temperatures, vibration, and water hammer).
- a. The Principal shall be consulted if a problem due to clean performance operation exists.

*A revision to the design or method of control might be required for these cases. Some typical problems that can occur are as follows:*

- *When throttling or bypassing flow, low velocity and fouling can occur. A larger temperature difference will also occur across the shell or channel when controlled in this fashion, and this can be detrimental due to the higher or lower outlet temperature than specified on the data/requisition sheet;*
  - *For steam-heated heat exchangers with a level control valve at the condensate outlet, inconsistent process control and/or water hammer can occur, particularly when the amount of surface area needed for the clean condition is less than approximately 25 % of the available surface;*
  - *For steam-heated heat exchangers with control valves at steam inlet, vibration (for shell side steam allocation) or erosion (for either shell or tube side steam allocation) might occur in the clean case, due to a decreased steam pressure, and associated increase in steam velocity;*
  - *Heat exchangers in series, particularly those with different materials specifications, might experience temperatures or pressures beyond the design conditions.*
26. The calculations of skin temperature and tube wall temperature shall reflect all operating cases, including the worst case operating condition considering clean operation, fouled operation, and operation of either side fouled with the other side clean.
27. For horizontal exchangers, if the sub-cooling duty constitutes 10 % or more of the overall duty for the condensing stream, then a separate exchanger should be incorporated to handle the sub-cooling duty.
- a. For horizontal heat exchangers where the sub-cooling duty is less than 10 % of the overall duty, the sub-cooling duty may be accomplished in a single shell
- For vertical heat exchanger arrangements, there are no limitations on sub-cooling duties.*
28. Loop seal piping, dam baffles, or process controls may be used to effect the flooding of heat transfer surface for sub-cooling.
29. Tube inserts should be used for services which require 100 % vaporization with in-tube boiling whenever either the superheat duty required is less than 20 % of the total heat duty for the exchanger or when the superheated outlet temperature is less than 50 °C (90 °F) above the dew point temperature.
- Tube inserts promote wetted wall flow regimes at high vapour qualities and mist flow conditions.*
30. Where condensation occurs when two immiscible liquid phases exist, the mixed phase liquid properties may be used for the thermal and hydraulic design calculations except as follows:
- a. When the aqueous phase comprises less than 20 % of the total liquid by mass, the thermal conductivity of the condensate film shall be based on the non-aqueous phase only.

## 2.4 FLUID ALLOCATION

1. The tube and shell-side stream allocation selection should be guided by Table 5.

*Swapping streams might be considered where there is an economic incentive to do so.*

*Traditionally, high fouling fluids are placed on the tube side, particularly where mechanical cleaning or highly effective hydro-blasting is required. However, where the high fouling stream or stream with suspended solids also has a high viscosity,*

*that stream might be placed on the shell side to reduce the surface area or number of shells required. A higher wall shear stress and U value can be achieved with the higher viscosity stream on the shell side, potentially reducing fouling tendency with a proper design. Attention to baffle design and maintaining low leakage stream flow fractions is critical in these situations.*

**Table 5 Stream placement**

| Service                          | Shell | Tube |
|----------------------------------|-------|------|
| Sea or brackish water            |       | X    |
| Cooling tower water              |       | X    |
| Lower allowable pressure drop    | X     |      |
| Larger flow w/similar properties | X     |      |
| High pressure                    |       | X    |
| Corrosive fluids                 |       | X    |
| Slurry service                   |       | X    |
| High viscosity                   | X     |      |
| Suspended solids                 |       | X    |
| Streams requiring water wash     |       | X    |
| Oxygen service                   |       | X    |

## 2.5 SHELL TYPE SELECTION

1. The shell type for most applications should be TEMA type E with segmental baffles; other shell types may be selected as follows:
  - a. Where the shell side pressure drop is a constraint, the divided flow shell TEMA type J, X, or H shells should be selected.
  - b. TEMA type G shells may be selected for slight amounts of temperature cross between the hot and cold fluids that could not otherwise be achieved using a TEMA type E shell, subject to approval by the Principal.
  - c. TEMA type J, X, H or G shells should be used for horizontal thermosiphons. TEMA type E shell thermosiphons may be considered when approved by the Principal.
  - d. TEMA type K type shells shall be selected for pool boiling applications (typically with 0 % to 5 % liquid entrainment) is required.
2. TEMA type F shells may be considered where the temperature profile of the process fluids requires two or more heat exchangers in series (temperature crossovers), or to increase the shell side velocity, subject to the following restrictions and approval by the Principal:
  - a. For design of new facilities, multiple shell pass designs should be applied only in services with non-removable bundles or removable bundles that will not require frequent disassembly for mechanical cleaning; i.e., shell side fluid has a very low, or low fouling tendency with fouling resistances  $\leq 0.00026 \text{ m}^2\text{-}^\circ\text{K/W}$  ( $0.0015 \text{ hr-ft}^2\text{-}^\circ\text{F/Btu}$ ).
  - b. For retrofit or debottlenecking of existing facilities, multiple shell-side pass designs may be considered for removable bundles with medium fouling fluids on the shell side.

- c. The maximum allowable shell-side pressure drop shall be less than 100 kpa (15 psi) for baffles which are continuously welded to the shell, or 50 kpa (7.5 psi) for baffles using flexible seals.
- d. The difference between the shell side inlet and outlet temperature shall not exceed 110 °C (200 °F).
- 3. Longitudinal baffles in fixed tubesheet exchangers shall be continuously welded to the shell.
- 4. Longitudinal baffles in removable bundle exchangers should utilize a double-sided, multi-layered clip-on spring set sealing device.
  - a. A single-sided multiple ply flexible seals or baffle seals attached by bolting may be used only when approved by the Principal.
- 5. Removable U-tube bundles provided with four (4) tube passes with the U-bends arranged in the horizontal plane may utilize welded-in longitudinal baffles when approved by the Principal.
- 6. Refer to DEP 31.21.01.30-Gen. clause 7.5.3.7, Item 4 for the thickness requirement of un-insulated welded-in longitudinal baffles.
- 7. The thermal leakage across the longitudinal baffle shall be included in the thermal design calculations.
- 8. The selection and design of an insulated longitudinal baffle shall be subject to the approval of the Principal.
  - a. An insulated longitudinal baffle (baffle composed of two plates, separated by spacers with a dead fluid zone between them or a single baffle with an insulation layer properly attached) should be considered when the thermal leakage exceeds 10 % of the mean temperature difference.
- 9. When used in two-phase flow shell side services the longitudinal baffle should be the insulated type.
  - a. Un-insulated baffles in two-phase flow shell side services may be considered when approved by the Principal.
- 10. For two-phase shell side flow, HTRI rating software does not calculate thermal leakage across a longitudinal baffle; supplemental design calculations shall be provided.

## 2.6 FRONT AND REAR HEAD TYPE SELECTION

*The use of removable tube bundles is generally preferred.*

- 1. Fixed tubesheet heat exchangers may be used only in services where all of the following conditions are satisfied:
  - a. Stresses caused by differential expansion between the tubes and the shell do not exceed the design stress limits for all design operating scenarios.
  - b. The shell side fluid has a very low, or low fouling tendency with fouling resistances  $\leq 0.00026 \text{ m}^2\text{-}^\circ\text{K/W}$  ( $0.0015 \text{ hr-ft}^2\text{-}^\circ\text{F/Btu}$ ) and not requiring mechanical cleaning.

*See DEP 20.21.00.31-Gen. for further information on fluid cleaning requirements.*
  - c. Shell side entry is not required for shell/nozzle inspection or maintenance.

*Some sour, wet H<sub>2</sub>S, or other potentially corrosive or materials degrading fluids might require shell internal inspection techniques and associated internal repairs, as equipment sizing allows.*

2. The use of expansion joints in fixed tubesheet exchangers to accommodate the differential expansion stresses is subject to the limitations indicated in DEP 31.21.01.30-Gen. section 7.9.
  - a. A floating-head type or U-tube type heat exchanger should be selected if the differential temperature induced stress limits cannot be satisfied with the use of fixed tubesheet.
3. Fixed tubesheet exchangers shall not be used when the expected tube bundle life is less than twice the anticipated process unit run lengths between turnarounds.
4. U-tube bundle heat exchangers may be used only in services where the following conditions are satisfied.
  - a. The tube side fluid's fouling tendency is not high or severe with a fouling resistance not exceeding  $0.00052 \text{ m}^2\text{-}^\circ\text{K/W}$  ( $0.003 \text{ hr-ft}^2\text{-}^\circ\text{F/Btu}$ ).
  - b. For tube side fluids with a medium fouling tendency, with a fouling resistance exceeding  $0.00026 \text{ m}^2\text{-}^\circ\text{K/W}$  ( $0.0015 \text{ hr-ft}^2\text{-}^\circ\text{F/Btu}$ ), a minimum nominal tube diameter of 25.4 mm (1 in) should be used with a centre-to-centre distance between the parallel legs of the U-tube is at least 4 times the tube outside diameter.
    - i. For tube side fluids with a medium fouling tendency, with a fouling resistance exceeding  $0.00026 \text{ m}^2\text{-}^\circ\text{K/W}$  ( $0.0015 \text{ hr-ft}^2\text{-}^\circ\text{F/Btu}$ ), tubes with a nominal tube diameter of 19.05 mm ( $\frac{3}{4}$  in) with a centre-to-centre distance between the parallel legs of the U-tube is at least 150 mm (6 in) may be used when approved by the Principal.
  - c. Tube side fluids with very low or low fouling tendencies, with a fouling resistance not exceeding  $0.00026 \text{ m}^2\text{-}^\circ\text{K/W}$  ( $0.0015 \text{ hr-ft}^2\text{-}^\circ\text{F/Btu}$ ).
5. U-tube bundles should be considered for all high pressure applications, typically greater than 6200 kPag (900 psig), regardless of tube side fouling tendency when it is economically attractive to do so and approved by the Principal.
6. Floating-head heat exchangers shall be used in all services for which fixed tubesheet or U-tube bundles are not allowed.
7. Shell diameters exceeding 1525 mm (60 in) for exchangers with removable bundles shall be subject to the approval of the Principal.
8. Removable channel covers should be specified on the stationary head of all heat exchangers having a tube side fluid with a medium or higher fouling tendency with a fouling resistance exceeding  $0.00026 \text{ m}^2\text{-}^\circ\text{K/W}$  ( $0.0015 \text{ hr-ft}^2\text{-}^\circ\text{F/Btu}$ ) and for all exchangers in cooling water service.
  - a. Exchangers with a nominal shell size not exceeding 450 mm (18 in) may be specified with bonnet covers on the stationary head regardless of fouling tendency when approved by the Principal.

*Site maintenance/cleaning practices might dictate the choice between the use of removable channel covers or bonnets and should be considered in the selection process when such preferences exist.*
9. For fixed tubesheet heat exchangers with an odd number of tube passes and a removable channel cover on the stationary head, the rear head shall also be specified with a removable channel cover.
  - a. For fixed tubesheet heat exchangers with an even number of tube passes, the rear head should be specified with a bonnet cover.

10. TEMA type C heads may be used on designs with a large number of tube side passes (typically 10 or more) to improve the reliability of the gasketed joint at the tubesheet.  
*Designs with a large number of tube side passes and gasket rib area makes it difficult to achieve the target gasket stresses due to the disparity between the tube and shell side gasket areas.*
11. TEMA type C heads should be used for tube side design pressures greater than 10.3 MPag (1500 psig).  
*Refer to (3.8) for additional information on high pressure design considerations.*
12. TEMA type C heads should be used when the temperature gradient across the tube side face of the tubesheet exceeds 140 °C (250 °F).
  - a. In such cases, an internally gasketed pass partition box shall be supplied so that the channel cover and bolting operate at a uniform temperature, typically at the lower tube side operating temperature.
  - b. A TEMA type N head may be used for non-removable tube bundles.
13. If the temperature gradient across the thickness of a tubesheet at any location exceeds 140 °C (250 °F), TEMA type C heads or other designs which eliminate a dual-gasketed seal between the tubesheet to the channel and shell should be used.
  - a. When high temperature differences can exist, the location of the shell inlet and outlet nozzles along the shell should be selected to minimize the temperature gradient across the tubesheet.
14. When a floating head exchanger is used, the choice between split ring and pull through types should be in accordance with the following:
  - a. Split ring TEMA type S for nominal shell diameters less than or equal to 760 mm (30 in);
  - b. Pull-through TEMA type T for nominal shell diameters greater than or equal to 1220 mm (48 in) and all kettle type heat exchangers regardless of diameter;
  - c. For shell diameters between these sizes a TEMA type T should be used unless a cross-flow (B-stream) flow fraction advantage of 0.1 or greater can be achieved through use of an S type.
15. TEMA type S floating heads should be limited to services below both the following design pressures:
  - a. 4100 kPag (600 psig) on the tube side;
  - b. 6200 kPag (900 psig) on the shell side.
16. TEMA type T floating heads should be limited to a design pressure on either side of 6200 kPag (900 psig).
17. TEMA type D or other closures may be considered in high-pressure tube side services, where they may be more economical than TEMA type A, B, C or N heads and subject to the following:
  - a. The Manufacturer/Supplier's proposed closure shall be approved by the Principal prior to purchase.
  - b. Refer to (3.8) for additional information on high pressure design considerations.
18. Where single pass floating head style exchangers are to be used, the tailpipe-to-shell cover seal shall be of the flanged or packed type.
  - a. The use of packed type joints is subject to the approval of the Principal and shall not be used for the following conditions:
    - i. Very toxic-acute services, per Part III of DEP 01.00.01.30-Gen.;