

DEP SPECIFICATION

# FOULING MARGINS IN TUBULAR HEAT EXCHANGER DESIGN

DEP 20.21.00.31-Gen.

February 2017

ECCN EAR99

## DESIGN AND ENGINEERING PRACTICE



© 2017 Shell Group of companies

All rights reserved. No part of this document may be reproduced, stored in a retrieval system, published or transmitted, in any form or by any means, without the prior written permission of the copyright owner or Shell Global Solutions International BV.

This document contains information that is classified as EAR99 and, as a consequence, can neither be exported nor re-exported to any country which is under an embargo of the U.S. government pursuant to Part 746 of the Export Administration Regulations (15 C.F.R. Part 746) nor can be made available to any national of such country. In addition, the information in this document cannot be exported nor re-exported to an end-user or for an end-use that is prohibited by Part 744 of the Export Administration Regulations (15 C.F.R. Part 744).

This document has been supplied under license by Shell to:  
UOP Honeywell ted.fuger@honeywell.com 19/01/2018 02:49:02

**AVA** Documents  
Document Sharing Hub

## PREFACE

DEP (Design and Engineering Practice) publications reflect the views, at the time of publication, of Shell Global Solutions International B.V. (Shell GSI) and, in some cases, of other Shell Companies.

These views are based on the experience acquired during involvement with the design, construction, operation and maintenance of processing units and facilities. Where deemed appropriate DEPs are based on, or reference international, regional, national and industry standards.

The objective is to set the standard for good design and engineering practice to be applied by Shell companies in oil and gas production, oil refining, gas handling, gasification, chemical processing, or any other such facility, and thereby to help achieve maximum technical and economic benefit from standardization.

The information set forth in these publications is provided to Shell companies for their consideration and decision to implement. This is of particular importance where DEPs may not cover every requirement or diversity of condition at each locality. The system of DEPs is expected to be sufficiently flexible to allow individual Operating Units to adapt the information set forth in DEPs to their own environment and requirements.

When Contractors or Manufacturers/Suppliers use DEPs, they shall be solely responsible for such use, including the quality of their work and the attainment of the required design and engineering standards. In particular, for those requirements not specifically covered, the Principal will typically expect them to follow those design and engineering practices that will achieve at least the same level of integrity as reflected in the DEPs. If in doubt, the Contractor or Manufacturer/Supplier shall, without detracting from his own responsibility, consult the Principal.

The right to obtain and to use DEPs is restricted, and is typically granted by Shell GSI (and in some cases by other Shell Companies) under a Service Agreement or a License Agreement. This right is granted primarily to Shell companies and other companies receiving technical advice and services from Shell GSI or another Shell Company. Consequently, three categories of users of DEPs can be distinguished:

- 1) Operating Units having a Service Agreement with Shell GSI or another Shell Company. The use of DEPs by these Operating Units is subject in all respects to the terms and conditions of the relevant Service Agreement.
- 2) Other parties who are authorised to use DEPs subject to appropriate contractual arrangements (whether as part of a Service Agreement or otherwise).
- 3) Contractors/subcontractors and Manufacturers/Suppliers under a contract with users referred to under 1) or 2) which requires that tenders for projects, materials supplied or - generally - work performed on behalf of the said users comply with the relevant standards.

Subject to any particular terms and conditions as may be set forth in specific agreements with users, Shell GSI disclaims any liability of whatsoever nature for any damage (including injury or death) suffered by any company or person whomsoever as a result of or in connection with the use, application or implementation of any DEP, combination of DEPs or any part thereof, even if it is wholly or partly caused by negligence on the part of Shell GSI or other Shell Company. The benefit of this disclaimer shall inure in all respects to Shell GSI and/or any Shell Company, or companies affiliated to these companies, that may issue DEPs or advise or require the use of DEPs.

Without prejudice to any specific terms in respect of confidentiality under relevant contractual arrangements, DEPs shall not, without the prior written consent of Shell GSI, be disclosed by users to any company or person whomsoever and the DEPs shall be used exclusively for the purpose for which they have been provided to the user. They shall be returned after use, including any copies which shall only be made by users with the express prior written consent of Shell GSI. The copyright of DEPs vests in Shell Group of companies. Users shall arrange for DEPs to be held in safe custody and Shell GSI may at any time require information satisfactory to them in order to ascertain how users implement this requirement.

All administrative queries should be directed to the DEP Administrator in Shell GSI.

**TABLE OF CONTENTS**

|           |                                                                |           |
|-----------|----------------------------------------------------------------|-----------|
| <b>1.</b> | <b>INTRODUCTION .....</b>                                      | <b>4</b>  |
| 1.1       | SCOPE .....                                                    | 4         |
| 1.2       | DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS ..... | 4         |
| 1.3       | DEFINITIONS .....                                              | 4         |
| 1.4       | CROSS-REFERENCES .....                                         | 7         |
| 1.5       | SUMMARY OF MAIN CHANGES.....                                   | 7         |
| 1.6       | COMMENTS ON THIS DEP .....                                     | 8         |
| 1.7       | DUAL UNITS.....                                                | 8         |
| 1.8       | NON NORMATIVE TEXT (COMMENTARY).....                           | 8         |
| <b>2.</b> | <b>BASICS OF USING A FOULING MARGIN .....</b>                  | <b>9</b>  |
| 2.1       | DEFINITION OF FOULING AND FOULING RESISTANCE.....              | 9         |
| 2.2       | ESTABLISHING FOULING MARGIN DURING DESIGN .....                | 9         |
| 2.3       | PRESSURE DROP MARGIN .....                                     | 9         |
| <b>3.</b> | <b>DESIGN METHODOLOGY .....</b>                                | <b>9</b>  |
| 3.1       | PROCESS MARGIN .....                                           | 9         |
| 3.2       | FOULING MARGIN.....                                            | 9         |
| 3.3       | DESIGN RULES .....                                             | 9         |
| 3.4       | PRESSURE DROP CONSIDERATIONS .....                             | 11        |
| 3.5       | DESIGN PRACTICES TO MINIMIZE FOULING .....                     | 11        |
| <b>4.</b> | <b>TABLES.....</b>                                             | <b>12</b> |
| <b>5.</b> | <b>REFERENCES .....</b>                                        | <b>35</b> |

**APPENDICES**

|                   |                                                             |           |
|-------------------|-------------------------------------------------------------|-----------|
| <b>APPENDIX A</b> | <b>FOULING MARGIN DESIGN METHODOLOGY FLOW CHART .....</b>   | <b>36</b> |
| <b>APPENDIX B</b> | <b>EXAMPLE OF FOULING MARGIN SPECIFICATION ON EDRS.....</b> | <b>37</b> |

## 1. INTRODUCTION

### 1.1 SCOPE

This DEP specifies practices to be followed during the design of tubular heat exchangers to provide allowances for fouling.

This is a revision of the DEP of the same number dated February 2015; 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 authorised access to DEPs does not for that reason constitute an authorisation 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 word **should** indicates a recommendation.

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

**1.3.2 Specific definitions**

| <b>Term</b>                                                    | <b>Definition</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|----------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Allowable Pressure Drop (<math>\Delta P_{allow}</math>)</b> | Pressure drop that is allotted for the heat exchanger in the hydraulic system design and process pressure profile                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>Design Fouling Resistance</b>                               | <p>A measure of the ultimate additional resistance to heat transfer caused by deposits on the heat transfer surface. It is commonly denoted by the symbol <math>R_f</math> and has the units <math>[m^2 \cdot ^\circ K/W \text{ or } ft^2 \cdot ^\circ F \cdot hr/Btu]</math></p> <p><i>The deposits may include a corrosion layer and may also depend on:</i></p> <p><i>The fluid deposits depends on</i></p> <ul style="list-style-type: none"> <li>• the type of fluid,</li> <li>• the presence of particulates and contaminants,</li> <li>• the heat-transfer surface material, the temperature conditions,</li> <li>• the flow velocities</li> <li>• the operating period between two successive cleaning actions.</li> </ul> |
| <b>Fouled Pressure Drop (<math>\Delta P_{fouled}</math>)</b>   | Pressure drop, estimated by using a multiplier ( $> 1.0$ ) on the clean pressure drop, to account for the increased flow resistance resulting from foulant deposition. The fouled pressure drop may be used in the final hydraulic system design.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>Fouling Margin</b>                                          | <p>The portion of the Margin which is specifically included to allow for the heat exchanger to perform the required heat duty in a fouled condition. Traditionally this margin has been provided by using design fouling resistances, which result in excess surface area.</p> <p><math>\% \text{ Fouling Margin} = 100 * (U_{clean}/U_{fouled} - 1)</math></p>                                                                                                                                                                                                                                                                                                                                                                    |
| <b>Margin</b>                                                  | The heat transfer surface area in excess of what is required by a heat exchanger to perform the design heat duty. The margin may be for fouling or for other uncertainties in the design such as fluid properties or variable process conditions.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>% Overdesign</b>                                            | $\% \text{ Overdesign} = 100 * (U_{fouled}/U_{required} - 1)$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>Pressure Drop Margin</b>                                    | A multiplier ( $> 1.0$ ) used on the calculated pressure drop to account for flow blockage created by fouling layers. The calculated "clean" pressure drop multiplied by this margin must be smaller than the allowable pressure drop.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <b>Process Margin</b>                                          | Margin specified by the Process Engineer to account for operational variations in flow rate and fluid composition, and sometimes for future capacity. It is specified as a percentage, and is accounted for in the design process by using a multiplier on the heat duty and the two flow rates.                                                                                                                                                                                                                                                                                                                                                                                                                                   |

| Term                                       | Definition                                                                                                                                                                                                                                                      |
|--------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Skin Temperature</b>                    | The temperature of the surface in contact with the fluid. In the clean condition this is the tube wall (metal surface) temperature, in a fouled condition it is the temperature at the surface of the fouling layer.                                            |
| <b>Total Equivalent Fouling Resistance</b> | The amount of final design margin, excluding process margin, converted to a fouling resistance using the formula $(1/U_{\text{required}} - 1/U_{\text{clean}})$ .                                                                                               |
| <b>% Total Excess Area</b>                 | $\% \text{ Total Excess Area} = 100 * (U_{\text{clean}}/U_{\text{required}} - 1)$                                                                                                                                                                               |
| <b>Uclean</b>                              | the overall heat transfer coefficient as determined by the individual stream heat transfer coefficients and tube metal resistance, with no allowances included for fouling                                                                                      |
| <b>Ufouled</b>                             | the overall heat transfer coefficient, as determined by the individual stream heat transfer coefficients, tube metal resistance, plus the additional resistance as allotted for fouling (either as margin or as an additional resistance as described in (3.2). |
| <b>Urequired</b>                           | the minimum overall heat transfer coefficient that is required for the heat exchanger to satisfy the prescribed process duty condition with the fixed heat transfer surface area which has been provided.                                                       |

**1.3.3 Abbreviations**

| <b>Term</b>  | <b>Definition</b>                   |
|--------------|-------------------------------------|
| <b>CAPEX</b> | Capital Expenditures                |
| <b>DEG</b>   | Di-Ethylene Glycol                  |
| <b>DIPE</b>  | Diisopropyl Ether                   |
| <b>DMK</b>   | Dimethyl ketone                     |
| <b>EDRS</b>  | Equipment Data Requisition Sheet    |
| <b>EHT</b>   | Enhanced Heat Transfer              |
| <b>HF</b>    | Hydrogen Fluoride                   |
| <b>IPA</b>   | Isopropyl Alcohol                   |
| <b>MIBK</b>  | Methyl Isobutyl Ketone              |
| <b>MOC</b>   | Management of Change                |
| <b>RHC</b>   | Residual Hydro-Conversion           |
| <b>TEFR</b>  | Total Equivalent Fouling Resistance |
| <b>TEG</b>   | Tetra Ethylene Glycol               |
| <b>TSRU</b>  | Tailings Solvent Recovery Unit      |

**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 MAIN CHANGES**

This DEP is a full revision of the DEP of the same number dated February 2015. The following are the main, non-editorial changes.

| <b>Section/Clause</b> | <b>Change</b>                                       |
|-----------------------|-----------------------------------------------------|
| All                   | Minor text editorial and update of informative data |
| 3.3.1                 | Rewrite of 4 and 5                                  |
| 3.3.4                 | Moved 1 2 3 to informative                          |
| 3.4                   | Updated definitions                                 |

## 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>Select a DEP and then go to the details screen for that DEP.<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://swwww.shell.com/standards">http://swwww.shell.com/standards</a> .<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. BASICS OF USING A FOULING MARGIN

### 2.1 DEFINITION OF FOULING AND FOULING RESISTANCE

1. A fouling margin shall be established during design (3) by one of the following methods:
  - a. design the exchanger without using a fouling factor, but instead add surface area to the design as a Fouling Margin, see definition in (1.3.2);
  - b. assign a fouling resistance to each fluid using either field derived values or Table 1B.

### 2.2 ESTABLISHING FOULING MARGIN DURING DESIGN

1. The fouling margins shall apply to shell and tube heat exchangers regardless of which side the fluid is on and for air-cooled heat exchangers on the tube side.

### 2.3 PRESSURE DROP MARGIN

1. A pressure drop margin should be provided in the hydraulic design of the overall system using the multipliers found in Table 4.

## 3. DESIGN METHODOLOGY

### 3.1 PROCESS MARGIN

1. The process design margin should be included in the design process duty conditions.

*This design condition is usually established through the inclusion of an additional percentage applied to heat duty and stream flow rates or as a different set of outlet conditions, as opposed to an arbitrary margin on surface area alone which does not assure that such a heat duty can be achieved.*

### 3.2 FOULING MARGIN

1. The fouling margin to be applied shall be based solely on the expected fouling propensity of the fluids; and not arbitrarily increased to account for other design margins.
2. The fouling margin shall be kept separate from any required process margin.

### 3.3 DESIGN RULES

#### 3.3.1 General

*Typical fluid streams encountered in Shell's operations are classified into five fouling level categories: Very Low (V) specified in Table 1A; and Low (L), Medium (M), High (H), and Severe (S), as specified in Table 1B.*

1. Table 1A lists the Very Low fouling services where normally no special design considerations for cleaning or access for cleaning are required.
  - a. Where Very Low fouling services are in two phase services, the practices in (3.5.2) should be given due consideration.
2. For heat exchangers where both fluids fall under the V, L, or M categories, the heat exchanger sizing shall be determined based upon the fouling margin (value selected from Table 1B) without the use of fouling resistance values.

3. The resulting total equivalent fouling resistance (see (1.3.2) and (APPENDIX B)) shall not be:
  - a. less than  $0.17 \times 10^{-3} \text{ m}^2\text{-C/W}$  ( $0.001 \text{ ft}^2\text{-F-hr/Btu}$ ) for carbon and low alloy steel tube materials or;
  - b. less than  $0.088 \times 10^{-3} \text{ m}^2\text{-C/W}$  ( $0.0005 \text{ ft}^2\text{-F-hr/Btu}$ ) for high alloy and non-ferrous tube materials.
4. If one or both fluids are in the H or S category, then fouling resistance values from Table 1B shall be used for both streams.
5. If the resulting fouling margin exceeds 50% for shell and tube heat exchangers or 30% for air cooled heat exchangers, the design should be submitted to the Principal for review.

*Principal could provide a reduction in the fouling resistance/margin for use.*

*(Appendix A) shows the application of the above steps in a flow chart format.*

### 3.3.2 Use of Design software

Note: The clean, fouled (as calculated during design), and required coefficients are in the order:

$$U_{\text{clean}} \geq U_{\text{fouled}} \geq U_{\text{required}}$$

1. To use the fouling margin approach (V, L, or M streams on both sides), fouling margin shall be represented by a percentage overdesign and not an input to the software program.
  - a. The total equivalent fouling resistance from the design shall be greater than the minimum specified in (3.3.1 item 3).
 

*Using this approach, the  $U_{\text{actual}}$  for the final design will exceed  $U_{\text{required}}$  by the appropriate fouling margin.*

*Since no fouling resistances are used, the design will have  $U_{\text{actual}} = U_{\text{clean}}$ .  $U_{\text{required}}$  is sometimes called  $U_{\text{service}}$ .*
2. If compliance with the design practices in (3.5) is not possible or practical, the design should be reviewed with the Principal's heat transfer specialist in order to determine appropriate fouling margins/resistances or design changes to be applied.

### 3.3.3 Cooling water heat exchangers

1. The minimum and maximum velocities and maximum skin and bulk temperatures presented in Table 5 shall be satisfied for each design case condition:
  - a. If hydraulic limitations dictate that a lower velocity than specified in Table 5 be used, Contractor shall provide alternatives to the Principal.
 

*Typically investigate whether actual water quality and the use of a higher fouling margin are reasonable options.*

    - i. Options shall not reduce velocity below 1.0 m/sec (3.3 ft/sec).
2. The design should be based on the lowest cooling water flow rate required for process control.
  - a. The cooling water side skin temperature should be maintained below the specified maximum value at the lowest cooling water flow rate required for process control.

### 3.3.4 Other considerations

1. When using the margin approach, if it is necessary to calculate tube metal or skin temperatures at design conditions, then after the design is finalized the fouling margin should be converted to the Total Equivalent Fouling Resistance (TEFR).
  - a. The TEFR value should be used in the calculation of temperatures in the fouled condition.

*It is left to the designer's judgement, based on which side fouls and how much conservatism is needed, to decide how to allocate the TEFR between the tube and shell sides.*

## 3.4 PRESSURE DROP CONSIDERATIONS

*The relationship between the pressure drops is:*

$$\Delta P_{\text{allow}} \geq \Delta P_{\text{fouled}} > \Delta P_{\text{clean}}$$

1. The design of the heat exchanger shall be such that the fouled pressure drop is lower than or equal to the allowable pressure drop.
  - a. The estimated increase in pressure drop above a clean condition due to fouling is provided by multiplying the calculated pressure drop for the clean condition by the appropriate pressure drop multiplication factor:
    - i. other than for cooling waters the listed factors from Table 4 shall be used;
    - ii. as applied to cooling water, other than in closed loop cooling systems, an applied pressure drop multiplier shall be as follows:
      - 1). 1.5 is to be applied for carbon and low alloy steel tube materials,
      - 2). 1.2 is for high-alloy and non-ferrous alloy tubes.
    - iii. For closed loop cooling systems, a pressure drop multiplier of 1.1 shall be applied.
2. Both the clean and fouled pressure drops shall be shown on the Equipment Data Requisition Sheet (EDRS).
3. The fouled pressure drop should be used in the final hydraulic system calculations.

## 3.5 DESIGN PRACTICES TO MINIMIZE FOULING

### 3.5.1 Velocity

1. Design should be with velocities higher than the minimum recommended liquid velocities shown in Table 3.

*For shell side flow, the velocity in Table 3 is the actual average cross-flow velocity based upon the main cross-flow stream fraction, excluding leakage streams.*

*Minimum velocity requirements, primarily for single phase liquids, assume the availability of a minimum pressure drop. DEP 31.21.01.12-Gen. and DEP 31.21.70.10-Gen. provide guidance on the selection of allowable pressure drop.*

2. In instances where the minimum velocity (3.5.1 Item 1) cannot be achieved due to constraints such as pressure drop, the appropriate design and design margin shall be developed in consultation with the Principal's heat transfer specialist.
3. In a two-phase flow, although high wall shear stress will be beneficial to prevent deposition and may aid removal of foulant, the design should avoid detrimental operating conditions such as flow induced tube vibration or film boiling mechanisms, which may impose lower limits on velocity.

**3.5.2 Skin temperature and heat flux**

1. The skin temperature shall be determined by using:
  - a. a simulation case in clean (zero fouling factor) conditions;
  - b. using the worst case conditions for heat exchangers controlled by flow bypass or heating medium temperature.
2. The skin temperature and heat flux limits specified in DEP 31.21.01.12-Gen. and DEP 31.21.70.10-Gen. shall be satisfied for the design case conditions.

*The fouling characterizations provided in this document are contingent upon respecting the recommended skin temperature and heat flux limits. Information on these limits can be found in DEP 31.21.01.12-Gen. and DEP 31.21.70.10-Gen.*

**3.5.3 Corrosion**

*There is often a strong dependency between surface corrosion and fouling. Preventing corrosion results in a smoother tube surface and minimizes deposition. Examples of fouling mitigation by reducing corrosion are the use of high Cr tubes where sulfidation corrosion is an issue and the use of alloy tubes in cooling water.*

**3.5.4 Geometry**

*Guidelines for the selection of geometric design choices and parameters are available in DEP 31.21.01.12 Gen. and DEP 31.21.70.10 Gen.*

1. Refer to Table 1B for each fluid, whether the following considerations for mechanical cleaning should be applied during a design.
2. The parameters which should be considered are:
  - a. fixed versus removable tube bundles;
  - b. tube diameter, tube spacing, and layout pattern;
  - c. straight versus u-tubes;
  - d. minimum radius of u bends;
  - e. channel closure type;
  - f. air cooled exchanger header box type.

**4. TABLES****Table 1A Services which require Very Low fouling margin**

|                                                                                                                                                                                                                                                 |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Process refrigerants – e.g., propylene, ethylene, Mixed refrigerant and propane in LNG plants (when compressors use dry-gas seals)                                                                                                              |
| Dehydrated natural gas in LNG plants                                                                                                                                                                                                            |
| Steam – utility grade                                                                                                                                                                                                                           |
| <p>Note:</p> <p>Services which require very low fouling margin do not require design geometries that allow for mechanical cleaning. Additional guidance for design of heat exchangers with these fluids is provided in DEP 31.21.01.12-Gen.</p> |