API 660 Addendum and Additions to the Published Standard (9th Edition)

**API Staff Note:** The following are the proposed additions to the published 9th Edition of Standard 660 to comprise Addendum 1 to cover High Temperature Hydrogen Attack (HTHA). The changes encompass the inclusion of a new normative Section (13) and the related additions to Sections 2, 3, Annex B and the Bibliography appearing below. The published 9th edition (a secured pdf) is included with this draft for comparison purposes.

**API Staff Note:** Proposed new normative reference.

## 2 Normative References

**API Staff Note:** Proposed two new definitions.

### 3 Terms and Definitions

- **3.xx** high temperature hydrogen attack (HTHA) service at elevated temperatures and pressures that can result in hydrogen dissociating and dissolving in steel, and then reacting with the carbon in solution in steel to form methane.

- **3.xx** high temperature hydrogen service (HTHS) steels operating at elevated temperatures and partial pressures in hydrogen environments.

**API Staff Note:** Proposed new Section 13.

### 13 Supplemental Requirements for Services Subject to High Temperature Hydrogen Service (HTHS)

#### 13.1 General

- **13.1.1** The purchaser shall specify if the additional HTHS requirements in Section 13 shall be applied to the shell and/or tube side of the heat exchanger. The operating limits of temperature and hydrogen partial pressure shall be within the limits included within the scope of API RP 941. See A.9 for additional guidance.

- **13.1.2** The requirements in previous sections of this document that address Hydrogen Service shall be applied.
13.2 Design Temperature

13.2.1 Design temperatures for each side subjected to HTHS shall be specified by the purchaser with considerations made for normal operating conditions, applied safety margins, alternate operating conditions and non-uniform fouling. See A.9.2.

13.2.2 Design temperatures shall not vary across a single heat exchanger shell, or from inlet channel to outlet channel of a single heat exchanger, unless specified by the purchaser. When variable design temperatures are specified, temperature monitoring points shall be provided at the design temperature breaks. See A.9.2.1.

13.2.3 For heat exchangers arranged in series, different design temperatures for each shell not be used unless specified by the purchaser. See A.9.2.1.

13.2.4 The design temperature for equipment subject to HTHS shall not be increased above the temperature used for material selection (see 13.3).

13.3 Materials

13.3.1 Materials shall be specified by the purchaser in accordance with API RP 941, including any design margins to be applied based on integrity operating window (IOW) limits. See A.9.3 and A.9.4.

13.3.2 When the shell side is in HTHS then the nominal composition of construction of the wetted surfaces shall not vary unless specified by the purchaser. When the tube side is in HTHS both channels shall be of the same nominal composition as the tubes unless specified by the purchaser. When different materials are used, temperature monitoring points shall be provided at the material breaks. See A.9.3.4.

13.3.3 For heat exchangers arranged in series, nominal composition shall not vary unless specified by the purchaser.

13.4 Connections for Temperature Indication

13.4.1 For heat exchangers arranged in series, flanged connections for temperature indication shall be provided in the interconnecting nozzles or interconnecting piping. These connections shall be provided for the side(s) in HTHS. (See A.9.5).

13.4.2 When specified by the purchaser, additional skin (metal) temperature measuring devices shall be provided. The quantity, location and type of device shall be agreed with the purchaser.

13.5 Fabrication

13.5.1 Weld details used on components in HTHS, including tubesheet to cylinder welds and nozzle assembly butt welds, shall be full penetration full fusion butt welds that can be 100 % volumetrically examined for the entire length.

13.5.2 Nozzle and auxiliary nozzle connections for components in HTHS shall be full penetration full fusion set through groove welds that can be 100 % volumetrically examined for the entire length.

13.5.3 Weld joint designs shall be capable of future in-service volumetric examination by either high frequency shear wave or angle-beam spectrum analysis techniques. Alternate examination methods may be agreed by the purchaser. The distance from the toe of the nozzle to cylinder weld to the toe of the nearest adjacent weld shall be a minimum of 50 mm (2 in.).

13.5.4 All components constructed of carbon steel and low-alloy steel shall be post-weld heat treated after completion of fabrication.
13.5.5 Dissimilar metal welds shall not be allowed in a single shell in HTHS. When construction is of varying materials in a single exchanger, as allowed in 13.3.2, then the welding and PWHT procedure shall be agreed between the vendor and purchaser taking account of the varying microstructure of the weld.

13.6 Inspection and Testing

13.6.1 All materials other than carbon steel, used for construction of the pressure retaining envelope and heat transfer tubes shall be verified by positive material identification. The extent and method to be agreed between purchaser and vendor.

13.6.2 All butt welds and nozzle attachment welds shall be 100% volumetrically examined after any required post-weld heat treatment.

13.6.3 Wet fluorescent magnetic particle examination shall be performed on the wetted surface for all pressure retaining welds after any required post-weld heat treatment. When the component is clad or weld overlay then the weld shall be wet fluorescent magnetic particle examined prior to back cladding.

13.6.4 Production hardness testing for all pressure retaining welds exposed to HTHS shall be performed in accordance with 10.1.6.

13.6.5 When specified by the purchaser, welds subject to HTHS shall be provided with baseline UT examination reports. The extent, locations and type of ultrasonic examination shall be as agreed with the purchaser. See API RP 941 Annex E for ultrasonic examination inspection methods.

13.6.6 When specified by the purchaser, a method to evaluate clad or weld overlay construction for susceptibility to hydrogen disbonding shall be agreed between the vendor and purchaser. The purchaser shall define testing requirements and acceptance criteria.

API Staff Note: Proposed additions to Annex A.

A.9 Additional Considerations for Specifying Parameters for High Temperature Service and HTHA

A.9.1 Introduction

HTHA is a potential material degradation mechanism that can result in surface decarburization, internal decarburization, fissuring or cracking of carbon and low alloy steels when subject to high temperature hydrogen service. For more information on HTHA, refer to API RP 571.

A.9.2 Additional conditions to be considered in setting maximum operating or design temperature – Guidance to 13.2

A.9.2.1 Most exchangers in services that are subject to HTHA are also subject to non-uniform fouling where the highest rate of the fouling occurs at the hot end of the process. In practice, design fouling factors used for initial design do not reflect this phenomena and fouling is applied as uniform across the exchanger. Operating data, if available, should be evaluated for non-uniform fouling trends and be applied to designs in similar services. Where historical data is not available, the designer should consider the effects of higher rates of hot-end fouling when predicting maximum exposure temperatures.

Similarly, if there are heat exchangers in series in high temperature service, designers sometimes assume operating conditions over the life of the plant based on the maximum expected degree of fouling. However, if the inlet exchanger in the series fouls more than expected and no longer cools the process stream sufficiently, the next exchanger(s) in the series might see higher temperatures than it was designed for. It
may then become susceptible to HTHA or other damage mechanisms for which the materials of construction may not be designed to handle.

A.9.2.2 Clean exchanger performance should be evaluated in the temperature analysis. When operating in the clean condition, the cold stream would be expected to exit the heat exchanger at temperatures above the expected process operating temperature unless external temperature controls are used.

A.9.2.3 When a hot bypass is required for process conditions (i.e. temperature control around the exchanger), the exchanger on the downstream side of the hot fluid requires detailed analysis to account for the uncooled material flowing through the bypass line. If flow bypass is not accounted for, then the downstream equipment on the hot fluid side may be exposed to unanticipated and undetected material degradation. Analysis of temperatures are required in both clean and fouled operating conditions.

A.9.2.4 When a cold bypass is required for process conditions (i.e. temperature control around the exchanger), in addition to A.9.2.3, the equipment requires a detailed analysis to account for the uncooled hot material in the exchanger. This can result in the exchanger operating above the material limits since the cooling fluid has been limited. Temperatures should be analyzed in both clean and fouled operating conditions.

A.9.3 Materials Selection for HTHA Services – Guidance to 13.3

A.9.3.1 Materials in contact with the process fluid in HTHS should be selected in accordance with API RP 941, which shows the limits for carbon steel without post weld heat treatment, carbon steel with post-weld heat treatment, various Cr-Mo steels and higher alloys. All other applicable damage mechanisms should also be reviewed for the final materials selection.

A.9.3.2 All operating modes should be considered to define the temperature and hydrogen partial pressure to be used in selecting materials per API RP 941.

A.9.3.3 A safety margin may be applied when using the API RP 941 curves, primarily due to the fact that the curves are based on empirical experiential data. This margin should, where available, be based on user experience or practices. If a clad or weld overlaid material is used, the base material should be resistant to the hydrogen conditions with no credit taken for the cladding or overlay.

A.9.3.4 For catalytic reforming feed effluent heat exchangers (commonly known as Texas Towers), that typically operating at pressures below 2050 kPa (ga) (300 psig) and with shell lengths greater than 15 m (50 ft), a material break in the shell is common. Operators should monitor the shell skin temperature by use of redundant temperature indicators located on the hot side of the material break. For exchangers with pressures above 2050 kPa (ga) (300 psig) or shell lengths less than 15 m (50 ft), material breaks are not recommended.

A.9.4 Establishing Integrity Operating Window (IOW) for services subject to HTHA – Guidance to 13.3.1

A.9.4.1 The establishment, monitoring, and maintaining of IOWs is a vital component of integrity management to control and prevent material degradation and assist in the exchanger inspection planning process, including risk-based inspection. See API RP 941.

A.9.4.2 Monitoring of equipment subject to HTHA requires that both chemical and physical operating parameters be examined including operating pressure, hydrogen partial pressure, and temperatures at specific locations of interest based on the exchanger and system design parameters and metallurgy.

A.9.4.3 As HTHA is a time-dependent degradation mechanism, a Standard IOW Limit is typically applied. If this limit is exceeded over a specified period of time, increased degradation rates or new damage
mechanisms could be experienced. Therefore, exceeding Standard IOW Limits may be acceptable over a specified (limited) period of time.

IOW Critical Limits are also applied, if this limit is exceeded rapid deterioration could occur. When IOW critical limits are exceeded, an alarm is generated, and immediate action is required to return the process variable(s) to within their IOW.

A.9.4.4 The establishment of IOW parameter limits in terms of operating temperature and hydrogen partial pressure for exchangers in HTHS depend upon many factors including the following:

- Materials of construction and any heat treatment applied.
- Previous history of HTHA for the exchanger.
- Safety margins that are applied to the API RP 941 guidelines for the selection of materials.
- Purchasers philosophy with respect to allowable duration of short-term exceedances of operating parameters used for material selection, e.g. end of run operation or catalyst sulfiding, etc.
- The length of time that equipment will be exposed to extreme or off normal operating conditions.
- Location and accuracy of temperature monitoring devices with respect to critical locations of temperature and/or materials of construction breaks, including influence of hot/cold stream by-passes.
- Effectiveness of inspection program to detect material degradation from HTHA.
- Effectiveness and rigor of heat exchanger/process monitoring program with respect to being able to accurately predict metal temperatures at specific locations where direct temperature indication is not available, including the consideration of non-linear heat exchanger fouling.

For more information on IOWs, refer to API RP 584.

A.9.5 Intermediate Temperature Connections – Guidance to 13.4

The installation of temperature indication and/or recording devices is essential for monitoring temperature trends between shells (or channels) of heat exchangers of the same materials.
**API Staff Note: Proposed additions to Table B.1.**

<table>
<thead>
<tr>
<th>Section</th>
<th>Item</th>
<th>Requirement</th>
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</thead>
<tbody>
<tr>
<td>13.1.1</td>
<td>Are the additional requirements specified in Section 13 required for the shell side?</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Are the additional requirements specified in Section 13 required for the tube side?</td>
<td>Yes</td>
</tr>
<tr>
<td>13.2.1</td>
<td>Specify the design temperatures for each side subjected to HTHS.</td>
<td></td>
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<tr>
<td>13.2.3</td>
<td>For exchangers in series are there different design temperatures specified for each shell; if yes, provide detailed information.</td>
<td>Yes</td>
</tr>
<tr>
<td>13.3.1</td>
<td>Specify if the nominal composition of construction of the wetted surfaces of either, or both, the shell side and tube side vary; if yes, provide detailed information.</td>
<td>Either</td>
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<tr>
<td>13.3.3</td>
<td>Specify if series heat exchanger nominal compositions vary; if yes, provide detailed information.</td>
<td>Yes</td>
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<tr>
<td>13.4.2</td>
<td>Specify if additional skin (metal) temperature measuring devices are required; if yes, detailed information to be agreed.</td>
<td>Yes</td>
</tr>
<tr>
<td>13.6.5</td>
<td>Specify if welds shall be provided with baseline UT examination reports. If yes, detailed information to be agreed.</td>
<td>Yes</td>
</tr>
<tr>
<td>13.6.6</td>
<td>Specify if a method to evaluate clad or weld overlay construction for susceptibility to hydrogen disbanding. If yes, provide detailed information.</td>
<td>Yes</td>
</tr>
</tbody>
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**API Staff Note: Proposed addition to the bibliography.**

**Bibliography**

[19] API RP 584, *Integrity Operating Windows*