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Affected Publication: API Standard 660, *Shell-and-Tube Heat Exchangers*, Ninth Edition, March 2015

Addendum 1

Section 2: The following normative reference shall be added:

API RP 941, *Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants*

Section 3: The following terms and definitions shall be added:

3.9

high temperature hydrogen attack

HTHA

Damage mechanism affecting carbon and low-alloy steels due to the exposure to hydrogen at elevated temperatures and pressures, resulting in the loss of carbides and strength of the materials and cracking.

3.10

high temperature hydrogen service

Services with operating hydrogen partial pressure above 350 kPa (50 psi) absolute and operating temperatures above 200 °C (400 °F).

Section 13: The following section shall be added:

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. 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** Material selection temperatures for each side subjected to HTHS shall be specified by the purchaser. See A.9.2.1.
- 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 otherwise specified by the purchaser. When variable design temperatures are specified, temperature monitoring points shall be provided at the design temperature breaks. See A.9.2.2.
- 13.2.3** For a heat exchanger unit arranged in series, different design temperatures for each shell shall not be used unless otherwise specified by the purchaser. See A.9.2.2.

13.3 Materials

- **13.3.1** Materials, including pressure-retaining internal components such as tubes, tubesheets, floating heads, and internal bellows, 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, the nominal composition of construction of the wetted surfaces shall not vary across a single heat exchanger shell, unless otherwise specified by the purchaser. When the tube side is in HTHS, channels shall be of the same nominal composition unless otherwise 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 material composition shall not vary between the different shells, unless specified by the purchaser.

13.4 Connections for Temperature Indication

13.4.1 For a heat exchanger unit arranged in series, where there are varying design temperatures or metallurgy, 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, skin (metal) temperature measuring devices, beyond what is required by 13.2.2, 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 connections for components in HTHS shall be full-penetration, full-fusion welds.

13.5.3 All components constructed of carbon steel shall be post-weld heat treated after completion of fabrication.

13.5.4 Dissimilar metal welds shall not be allowed in a single shell in HTHS, except as allowed in 13.3.2. When dissimilar materials are used, 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 shall be agreed between purchaser and vendor.

13.6.2 All butt 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 accessible wetted surfaces, for all carbon or low-alloy steel pressure-retaining welds, after any required post-weld heat treatment. When the component is clad, the base material weld shall be wet fluorescent magnetic particle examined prior to restoration of the cladding. When the minimum required preheat temperature is above the limits of

wet fluorescent magnetic particle solution, a dry magnetic particle method may be used prior to the restoration of the cladding.

13.6.4 Production hardness testing for all pressure-retaining welds and heat-affected zones 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, clad and weld overlay construction shall be tested for susceptibility to hydrogen disbonding. The testing requirements and acceptance criteria shall be agreed between the purchaser and vendor.

Annex A: The following sections shall be added:

A.9 Additional Considerations for Specifying Parameters for High Temperature Hydrogen Service

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 Setting Maximum Operating or Design Temperature—Guidance to 13.2

A.9.2.1 Material selection temperatures should be made with considerations made for normal operating conditions, applied safety margins, alternate operating conditions, and non-uniform fouling.

A.9.2.2 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 hottest 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 suitable. For additional information on damage mechanisms, see API RP 571.

A.9.2.3 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.9.2.4 When a hot bypass is required for process conditions (i.e. temperature control around the exchanger), the exchanger on the downstream side of the reintroduction of the bypass of the hot fluid requires detailed analysis to account for the uncooled material flowing through the bypass line. If a flow bypass is not accounted for, 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.9.2.5 When a cold bypass is required for hot stream outlet temperature control, in addition to A.9.2.4, the equipment requires a detailed analysis to account for the additional heating and higher outlet temperature of the cold fluid that passes through the exchanger, prior to remixing with the bypass stream. 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. All other applicable damage mechanisms should also be reviewed for the final materials selection. For additional information on damage mechanisms, see API RP 571.

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 experience-based data. This margin can, 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 Material breaks are not recommended for exchangers operating in high temperature hydrogen service.

A.9.3.5 For catalytic reforming feed effluent heat exchangers (commonly known as Texas towers) that typically have shell lengths greater than 15 m (50 ft) and a large operating temperature change from inlet to outlet, a material break in the shell is sometimes used. Operators should monitor the shell temperature by use of redundant temperature indicators located on the hot side of the material break. The location, quantity, and type of temperature indicator, e.g. thermowells or skin temperature, should be specified by the purchaser.

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 and API RP 584.

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. All such cases should be tracked to understand the cumulative effect.

There may be cases where the exchanger mechanical design temperature(s) are higher than the temperatures indicated in the equipment IOWs. Care must be exercised to refer to the IOW temperature limits and not only the mechanical design temperatures when considering operating temperature changes for exchangers in high temperature hydrogen service.

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 for new heat exchangers in terms of operating temperature and hydrogen partial pressure for exchangers in HTHS depends upon many factors, including the following:

- a) materials of construction and any heat treatment applied.
- b) previous history of HTHA for the intended service.
- c) safety margins that are applied to the API RP 941 guidelines for the selection of materials.
- d) purchaser's 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..
- e) the length of time that equipment will be exposed to extreme or off normal operating conditions.
- f) 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 bypasses.
- g) effectiveness and rigor of the 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 recording devices is essential for monitoring temperature trends between shells (or channels) of a heat exchanger unit to ensure operating within the IOW limits.

Table B.1: The following rows shall be added:

13.1.1	Are the additional requirements specified in Section 13 required for the shell side?	Yes	No
	Are the additional requirements specified in Section 13 required for the tube side?	Yes	No
13.2.1	Specify the design temperatures for each side subjected to HTHS.		
13.3.1	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.	Either	Both
13.4.2	Specify if skin (metal) temperature measuring devices are required. If yes, detailed information to be agreed.	Yes	No
13.6.5	Specify if welds shall be provided with baseline UT examination reports. If yes, detailed information to be agreed.	Yes	No
13.6.6	Specify if clad or weld overlay construction shall be tested for hydrogen disbonding. If yes, provide detailed information.	Yes	No

Bibliography: The following entry shall be added:

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