



CSB Safety Alert: Preventing High Temperature Hydrogen Attack (HTHA)

Background & Investigation Findings

The U.S. Chemical Safety and Hazard Investigation Board (CSB) has found that inadequate mechanical integrity programs, including preventive maintenance to control damage mechanisms and aging equipment at chemical facilities, have been causal to incidents investigated by the CSB. The CSB's investigation into the catastrophic failure of a forty-year-old heat exchanger at the Tesoro Refinery in Anacortes, Washington, determined that the fatal explosion and fire was caused by a damage mechanism known as high temperature hydrogen attack, or HTHA, which severely cracked and weakened the carbon steel heat exchanger over time, leading to a rupture.¹

Industry uses a standard for determining vulnerability of equipment to HTHA, known as American Petroleum Institute (API) Recommended Practice (RP) 941, *Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and the Petrochemical Plants*. The standard uses "Nelson Curves" to predict the operating conditions where HTHA can occur in different types of steels. The curves are based on process data voluntarily reported to API, and are drawn beneath reported occurrences of HTHA to indicate the "safe" and "unsafe" operating regions. The CSB investigation identified that Tesoro, like others in the industry, used API RP 941 to predict susceptibility of equipment to HTHA damage. The CSB found that HTHA occurred in the Tesoro heat exchanger in the "safe" operating region – where API RP 941 did not predict HTHA to occur.

Predicting and identifying equipment damage due to HTHA is complex. The CSB concluded in its investigation of the Tesoro Anacortes incident that using inherently safer materials of construction is the best approach to prevent HTHA. The carbon steel Nelson curve has repeatedly proven to be unreliable to predict HTHA. For example, the 2016 edition of API RP 941 reports 13 new failures below the carbon steel Nelson curve. In addition, inspecting for HTHA is difficult because the microscopic cracks can be localized and hard to identify. The CSB concluded that inspections should not be relied on to identify and control HTHA, as successful identification of HTHA is highly dependent on the specific techniques employed and the skill of the inspector, and few inspectors were found to have this level of expertise.

As a result of its findings, the CSB made a recommendation to API to further prevent the occurrence of HTHA by revising RP 941 as follows:

CSB Recommendation No. 2010-8-I-WA-R10:

Revise American Petroleum Institute API RP 941: Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants to:

- a. Clearly establish the minimum necessary "shall" requirements to prevent HTHA equipment failures using a format such as that used in ANSI/AIHA Z10-2012, Occupational Health and Safety Management Systems;*
- b. Require the use of inherently safer materials to the greatest extent feasible;*
- c. Require verification of actual operating conditions to confirm that material of construction selection prevents HTHA equipment failure; and*
- d. Prohibit the use of carbon steel in processes that operate above 400 °F and greater than 50 psia hydrogen partial pressure.*

¹ Further information on the CSB's Tesoro Anacortes Refinery Explosion and Fire can be found at: <http://www.csb.gov/tesoro-refinery-fatal-explosion-and-fire/>.

Catastrophic HTHA Equipment Failure Can Still Occur Using the New API Nelson Curve

In February 2016, API published the 8th edition of RP 941. Though this updated guidance does provide incremental improvements, it does not address important elements of the CSB's recommendation. In the 2016 version, there are now two carbon steel Nelson curves, distinguished by whether the equipment has been post-weld heat treated (PWHT). API's curve for non-PWHT carbon steel is drawn below the 13 newly reported failures. This Nelson curve does not, however, take into account all of the estimated process conditions where catastrophic failure occurred due to HTHA at the Tesoro Anacortes Refinery. As a result, the new curve allows refinery equipment to operate at conditions where HTHA severely damaged the Tesoro heat exchanger. The use of a curve not incorporating significant failure data could result in future catastrophic equipment ruptures.

In addition, the updated standard does not establish minimum requirements to prevent equipment failure due to HTHA or require the use of inherently safer materials. API already identifies materials that are not susceptible to HTHA failure in API 571.² The CSB ultimately believes that the stronger option for industry to protect against HTHA is to focus on upgrading equipment susceptible to HTHA with inherently safer materials of construction rather than simply relying on administrative controls. Not only is HTHA very difficult to detect but equipment inspections and post-weld heat-treating rely on procedures and human implementation, which are low on the hierarchy of controls. These options are weaker safeguards to prevent HTHA failures than the use of materials that are less susceptible to HTHA damage. As a result of these noted deficiencies, the Board voted on July 13, 2016, to designate Recommendation 2010-08-I-WA-R10 with the status of **Closed – Unacceptable Action**.

In the absence of a carbon steel Nelson Curve that adequately protects against HTHA and incorporates findings from the Tesoro Anacortes failure, the CSB provides the following guidance for industry:

CSB Safety Guidance to Prevent HTHA Equipment Failure:

1. Identify all carbon steel equipment in hydrogen service that has the potential to harm workers or communities due to catastrophic failure;
2. Verify actual operating conditions (hydrogen partial pressure and temperature) for the identified carbon steel equipment;
3. Replace carbon steel process equipment that operates above 400 °F and greater than 50 psia hydrogen partial pressure; and
4. Use inherently safer materials, such as steels with higher chromium and molybdenum content.

Inadequate mechanical integrity programs were causal to several recent incidents investigated by the CSB. In its "Most Wanted Safety Improvements," the CSB identifies Preventive Maintenance—which includes actions to effectively control damage mechanisms—as a critical industry-wide improvement to prevent catastrophic incidents. The CSB also calls on regulators to modernize U.S. Process Safety Management regulations, including requiring inherently safer systems analyses, as a way to prevent catastrophic equipment failures. More information about these safety topics is available at: <http://www.csb.gov/mostwanted/>.

² API RP 571 states, "300 Series SS, as well as 5Cr, 9Cr and 12 Cr alloys, are not susceptible to HTHA at conditions normally seen in refinery units. Name of 571 in Anacortes, what those materials have, in Anacortes. API RP 571. *Damage Mechanisms Affecting Fixed Equipment in the Refinery Industry*. 2003; p 5-83.