

Factors to Consider When Managing High Temperature Hydrogen Attack on Petroleum and Chemical Facilities

Publication 240

Edition 1

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ISBN 978-0-85931-229-5

Imprint reference 01-2019
First published 01-2019

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Preface

The accident at Tesoro Anacortes Refinery in 2010 in which seven people lost their lives raised a number of issues about managing the integrity of plant potentially affected by High Temperature Hydrogen Attack. The issues are mainly focussed on carbon steel welds that have not been stress relieved before entering service.

The UK competent authority (Health & Safety Executive) has asked operators to ensure that they are managing HTHA in-line with latest guidance and recommendations and are considering what actions represent good practice in the UK.

This publication provides some background information and related specific elements of managing HTHA and provides a “checklist” of issues that have been identified within an EEMUA Forum on HTHA. It is intended to supplement company policies and procedures and assist facility personnel to manage equipment exposed to HTHA. It is intended to contribute towards good practice guidance.

This Publication focusses primarily on equipment constructed from carbon steel though aspects of the contents are generally relevant to equipment constructed from other materials.

Acknowledgements

This guidance is based on information provided and discussed during a series of meetings of the EEMUA HTHA Forum made up of representatives from operators of major refineries in the UK and Ireland. The guidance reflects the discussions and also reflects general information from published articles and papers on the subject.

The Forum established contact with the UK's competent authority (HSE), members of the API 941 committee and a number of the Joint Industry Programmes and contributors during its deliberations and the preparation of this guidance. Their opinions and advice were gratefully received. It should however be made clear that this guidance does not claim to represent the positions of these bodies on managing HTHA.

Abbreviations/Acronyms used in this Guide

ABSA	Angle Beam Spectral Analysis
API	American Petroleum Institute
AUBT	Advanced Ultrasonic Backscatter Technique
BINDT	British Institute of Non-Destructive Testing
C&I	Control and Instrumentation
CSB	U.S. Chemical Safety and Hazard Investigation Board
D/FPI	Dye/Fluorescent Penetrant Inspection
E2G	The Equity Engineering Group Inc.
FMC	Full Matrix Capture
HSE	UK Health and Safety Executive
HTHA	High Temperature Hydrogen Attack
IOW	Integrity Operating Window
IR	InfraRed
JIP	Joint Industry Project
MPI	Magnetic Particle Inspection
MTI	Materials Technology Institute
NACE	National Association of Corrosion Engineers
NDE	Non-Destructive Examination
NDT	Non-Destructive Testing
PAUT	Phased Array Ultrasonic Testing
ppH ₂	Partial Pressure of Hydrogen
P _v	A damage parameter for High Temperature Hydrogen Attack
PWHT	Post Weld Heat Treatment
QA	Quality Assurance

RP	Recommended Practice
SES	Stress Engineering Services Inc.
TFM	Total Focussing Method
TOFD	Time Of Flight Diffraction
TWI	The Welding Institute
UT	Ultrasonic Testing

1 Introduction

High Temperature Hydrogen Attack (HTHA) is a well-known time dependant degradation mechanism that can affect the integrity of steels used for pressure containment in petrochemical facilities operating above about 400°F (204°C). The likelihood of damage occurring is mainly influenced by operating time, temperature, hydrogen partial pressure (ppH₂), steel composition and applied and residual stresses – particularly where these have not been relieved after section forming or after welding.

API RP 941¹ currently provides guidance for steel selection (and so susceptibility to attack) in relation to temperature and ppH₂ via Nelson curves. Following the inquiry² (and see footnote*) into the Anacortes accident by the US Chemical Safety Board (CSB) the most recent Edition (8th) contains a new curve for “Carbon steel (welded with no PWHT)”. This sits approximately 50 psi to the left and 50-100°F (28-56°C) below the previous carbon steel curve so reducing the design allowable temperatures and pressures. It also represents a new susceptibility assessment line for existing plant that encompasses a larger number of plant items that now require to be managed for HTHA. The previous carbon steel curve is now retitled “Carbon steel (non-welded or welded with PWHT)”. Annex F of the RP states that owners/operators may choose to replace equipment or prioritise such equipment operating above the new curve for inspection. This latter option however presupposes that effective inspection regimes are available and can be safely applied within the damage development rates. Management can involve replacing susceptible items, inspecting for signs of HTHA and reducing operating parameters.

The new curve in the 8th Edition does not however match the recommendations made by the CSB who later reiterated their proposal in a Safety Bulletin³ for a much lower line and recommended replacement of carbon steel process equipment operating above 400°F (204°C) and greater than 50psia ppH₂. Following this, the competent authority in the UK, the Health & Safety Executive (HSE) visited refinery facilities to assess their current HTHA actions. The HSE also engaged The Welding Institute to review HTHA and provide advice that would inform the HSE’s expectations of good practice in managing the issue.

A Safety Alert⁶ issued recently by the HSE states that: *For existing plant, API RP 941 8th Edition can be regarded as ‘relevant good practice’, and the Nelson curves can be used to help define a safe operating envelope for steels on hydrogen service. However the curves should be used with some caution, and their use is dependent on a number of factors which should be taken in to consideration when assessing risk and developing a management strategy:...* The Alert lists factors to be considered and action required.

This EEMUA publication addresses the areas referred to in the Alert and provides general guidance in those areas, however, users of this publication should satisfy themselves that they are meeting the specific requirements of the Alert in all cases.

*At various stages this document draws on the Investigation Report into the Anacortes accident issued by U.S. Chemical Safety and Hazard Investigation Board to which the reader is referred to for more detailed information.

1.1 Purpose

In response, EEMUA refinery members formed an HTHA Forum to work together on the issue and provide a platform for:

- Establishing current practices in the UK
- Identifying where these may differ between member companies
- Liaison between HSE and the members
- Contact with API 941 Committee and various Joint Industry Projects in the US and Europe that are driving HTHA research and guidance
- Facilitating contact between HSE's contractor (The Welding Institute) who are advising HSE on material and NDE aspects, and the API and members who have up to date information and experience on HTHA
- Providing a collective "voice" to represent the members with the HSE
- Describing elements of good practice

1.2 Scope

The Forum has met on a number of occasions and through sharing information and experience has identified a number of factors that deserve particular attention when managing the problem.

This Publication provides a description of these factors as they currently stand – future updates may be published. It was not the role of the Forum to provide technical solutions to issues (which are being dealt with by refinery companies in conjunction with API Committees and the various Joint Industry Projects, JIPs) but to highlight areas to members where knowledge of different approaches and increased awareness in managing the problem at facility level are beneficial to delivering good practice.

1.2.1 Note on Carbon 0.5Mo Steels

The Nelson curves for Carbon 0.5Mo steels were deleted from API RP 941 in the fourth edition (1990). This was due to cases of HTHA damage in 0.5Mo steel equipment occurring as much as 200°F (111°C) below the curve. The advice, which hasn't changed in the current edition, is that existing C-0.5Mo steel equipment that is operated above the PWHT'd carbon steel curve (i.e. that previously labelled carbon steel) should be inspected to detect HTHA. Future editions are expected to include age based curves for C-0.5Mo steels in the non-PWHT'd and PWHT'd conditions. It is quite possible that these will show a lowering of the current position for the non-PWHT'd condition, requiring additional actions to be taken by operators of such equipment.

1.3 Joint Industry Projects

A number of industry sponsored projects are running on HTHA and these are variously referred to throughout this guidance. Known projects are listed below and readers are advised to contact the associated organisations for further information of the full content of the projects which may not be fully reflected or described in this guidance. API is also funding research work.

Equity Engineering (including Lavender International)
Stress Engineering Services
Materials Technology Institute
The Welding Institute (proposal)

2 General Considerations

2.1 Time Dependency

The Nelson curves are based on reported HTHA failures, damage or freedom of damage from inspections collated over many years by operators. Reporting may not however be comprehensive and the curves do not specifically account for operating time. Whilst they provide a reasonable approach at the design/material selection stage they are less helpful for assessing in-service equipment as the damage is time dependant with a period of incubation when incipient damage is developing. There is some evidence that high residual stress from section forming or welding without stress relief or PWHT reduces the incubation period. Future Editions of API RP 941 may address this with more information on incubation models. Other variables that are not addressed by the curves that could affect the susceptibility to HTHA, include for example, carbide stability, grain size, material compositions, thickness, heat treatment states, type of weld.

An HTHA damage parameter, P_v , is described in literature⁴ for C-0.5Mo steel that relates operating time, ppH₂ and temperature and provides a possible means of ranking the susceptibility of equipment in service to HTHA damage. However, in its original form the parameter is not thought to adequately account for applied stress and particularly residual welding stresses which can be at or near yield stress level and are implicated in driving the more rapid development of fissures and cracking. The parameter was described in the previous editions of API RP 581⁵ guidance but is not present in the current editions. A few Forum members have retained and further developed the damage parameter approach to assist with particular assessment cases of C-0.5Mo steel in specific heat treatment states.

A JIP run by Stress Engineering Services has an element aimed at providing a time dependant through life HTHA damage model which will be available to sponsors. Equity Engineering are running a different JIP which includes delivering a life assessment model with the potential use in fitness for service appraisals. These models are currently under development and experience in their use will be needed to demonstrate their effectiveness.

2.2 Damage Development

At high temperature, molecular hydrogen can dissociate into atomic hydrogen at the metal surface and diffuse into the microstructure of steel where it may react with carbides at grain boundaries to form methane which has a larger molecule size and cannot readily diffuse out of the steel. Methane pressure builds up creating high stresses along grain boundaries which can exceed material strength and cause intergranular fissuring. Given time, atomic hydrogen can penetrate deep into the steel which can result in fissures developing to appreciable through wall extents. As the concentration of fissures builds up at any point they may eventually amalgamate to create micro-cracks which in turn may link and potentially lead to failure. The extent of fissuring damage ahead of established cracking could clearly influence the rate of crack propagation. Fissuring, amalgamation and the development and propagation of cracks may be accelerated by stresses present in the materials (including residual forming and welding stresses).