Detection of In-service Wet H$_2$S Cracking at Reboiler Shell
Weldment using Phased Array Ultrasonic Testing (PAUT)

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Abstract

Wet H$_2$S cracking covers a range of damage mechanisms that can occur due to the effects of aqueous hydrogen charging in wet H$_2$S refinery process environments. Types of damage that can occur as a result of aqueous hydrogen charging include sulphide stress cracking (SSC) of hard weldments and microstructures, hydrogen induced cracking (HIC) and stress oriented hydrogen induced cracking (SOHIC). With the changes in refining technology i.e. shifting towards more and more H$_2$ based technology particularly when processing opportunity crude, the wet H$_2$S related problems and its mitigation methods are getting prime importance. However, due to the orientation of these step wise cracks, the timely detection of these cracking phenomena remains a challenge to the NDT personnel as most of the conventional NDTs like radiography or ultrasonic flaw detection often fails to detect these type of damages.

Wet H$_2$S cracking phenomenon was experienced in one of the Reboiler circuits in Once through Hydro Cracking Unit (OHCU) due to accidental water carry-over. To detect the extent of damage, Phased Array Ultrasonic Testing (PAUT) was employed. The phased array system, in contrast to conventional ultrasonic system, uses a transducer assembly of multiple elements which can be pulsed separately in such a way that the individual wave fronts generated by each element in the array combine with each other to add or cancel energy in predictable ways that effectively steer and shape the sound beam. The Phased Array system could detect the cracks in weldments and repairs could be carried out, thereby increasing the reliability of the equipments. The paper describes the effective use of Phased Array Ultrasonic Testing (PAUT) in detecting the wet H$_2$S cracking of Reboiler shell in Once through Hydro Cracking Unit.

Introduction

The Wet H$_2$S cracking problem in oil industry was first recognized in the 1970’s and guidance on material requirements to avoid SSC was published at that time by NACE as MR0175 (Materials for use in H$_2$S containing environments in oil and gas production). Since then, a better appreciation of the consequences of wet H$_2$S damages has been ascertained because handling of H$_2$S rich process streams in oil industry has a safety consequence also. The prevention of sulphide stress cracking is mainly accomplished by appropriate materials selection, e.g. in accordance with NACE MR0103 (Materials resistant to Sulphide Stress cracking in corrosive Petroleum Refining Environments). In addition, the weld hardness should be controlled, in accordance with NACE RP0472 (Methods and Controls to prevent in-service Environmental cracking of carbon steel weldments in corrosive Petroleum Refining Environments). This usually involves appropriate controls in the welding procedures (e.g. preheat, weld heat input and PWHT etc.). Post weld heat treatment (PWHT) is often used to reduce the likelihood of cracking of steel even further. PWHT significantly reduces residual stresses and also tempers (softens) weld deposits and HAZs. A PWHT of about 620$^\circ$ C (1150$^\circ$ F) for one hour per 25 mm (1 inch) of thickness is considered to be effective for carbon
steel. Higher temperatures are required for low alloy steels in accordance with the ASME sec VIII Div 1. The Wet H₂S Cracking problem in oil refineries and gas plants cover a range of damage mechanisms that can occur due to the effects of aqueous hydrogen charging in Wet H₂S process environments (refinery or gas plant). Types of damage that can occur as a result of aqueous hydrogen charging include sulphide stress cracking (SSC) of hard weldments and microstructures, hydrogen blistering, hydrogen Induced cracking (HIC) and stress-oriented hydrogen induced cracking (SOHIC).

The use of cracking resistant materials with proper stress relieving in the wet H₂S services has considerably reduced the possibility of catastrophic failure due to cracking. However, in case of process upsets, accidental carry over of moisture in H₂S environment makes the system susceptible to wet H₂S cracking, since the system is not designed for it. One such case of accidental carry over of water from Main Fractionator Overhead Reflux Drum of Once Through Hydro Cracker Unit (OHCU) to the Main Fractionator Column, Naphtha Stripper Column and Debutanizer Column resulted in wet H₂S environment in the reboiler circuits of the Columns for which the system was not designed. A through crack was developed at the shell of one of the reboilers. To determine the extent of wet H₂S damage in the entire circuit comprising of the reboilers and piping, Phased Array Ultrasonic Testing (PAUT) was employed during the emergency shutdown. A number of cracks could be detected by PAUT which were repaired as per standard procedure followed by PWHT of the entire circuit.

The paper focusses on the effective use of Phased Array Ultrasonic Testing (PAUT) in detecting the wet H₂S cracking at different stages of propagation. The paper also emphasises the consideration of operational upsets during the basic engineering design stage to avoid catastrophic failures in future.

**Background**

Once Through Hydro Cracker Unit (OHCU) processes blends of heavy distillates to maximize LPG and Diesel production through hydrogenation and hydro cracking reactions. In one of the process upsets in the Unit, the boot level of Main Fractionator Overhead Reflux Drum showed sharp increase leading to water carry over in the downstream circuits along with process stream. A part of the downstream circuit, mainly the reboiler circuits of Main Fractionator Column, Naphtha Stripper Column and Debutanizer Column were not designed for wet H₂S service. In a few days after the carry over incident, a crack was observed at the bottom portion of the shell of Debutanizer Reboiler leading to emergency shutdown of the Unit. The crack was along one of the the circumferential weld of the shell (Figure # 1). The Dye Pentrant test revealed the length of the crack to be about 3 inches (Figure # 2).

![Figure # 1: The crack as seen from outside](image1)

![Figure # 2: Penetrant test revealing the crack](image2)
After pulling out of the tube bundle, the shell was inspected from the inside surface. The crack was found to be at the HAZ of the weld. The crack was found to have propagated in a zig-zag manner along the HAZ (Figure # 3). The Wet Fluorescent Magnetic Particle Inspection (WFMPI) revealed the crack length of about 12 inches from inside surface.

Since the reboilers and their connected piping were not designed for wet H$_2$S service, it was decided to carry out Phased Array Ultrasonic Testing (PAUT) of the reboiler shells and the connected piping to ascertain all deteriorations that could have possibly happened in the entire circuits.

**Wet H$_2$S cracking**

The key characteristic of Wet H$_2$S cracking mechanisms involve charging of the steel with hydrogen at relatively low temperatures, most often as the result of corrosion process, which evolves hydrogen. The role of the H$_2$S is to poison the hydrogen recombination reaction that would ordinarily occur and force the hydrogen atom to enter the metal structure rather than bubble off from the corroding surface. Wet H$_2$S cracking occurs under acidic conditions like present in oil field applications. Often, arrays of cracks are formed at different planes which interconnect to form step-wise cracking finally resulting in through thickness cracks. The conventional method of detecting wet H$_2$S cracking is Wet Flourescent Magnetic Particle testing (WFMPI) which can detect sub-surface cracks. However, for piping and other components which are internally not approachable, Phased Array Ultrasonic Testing (PAUT) remains the most convenient and reliable non-destructive method for detection of such cracks.

**Phased Array Ultrasonic Testing**

The phased array ultrasonic system utilizes the phasing principle of wave physics. In phased array ultrasonic method, the probe/search unit comprises multiple transducers arranged along a straight line. The time between a series of outgoing ultrasonic pulses is varied in such a way that the individual wavefronts generated by each element in the array combine with each other. This action adds or cancels energy in predictable ways that effectively steer and shape the sound beam. This is accomplished by pulsing the individual probe element at slightly different times. The software controlled programmed pulsing sequence launches a series of individual wavefronts in the test material. The wavefronts, in turn, combine constructively and destructively into a single primary wavefront that travels through the test material and reflects off the cracks, discontinuities etc like conventional ultrasonic wave (Figure # 5). The beam can be dynamically steered through various angles, focal distances and focal spot sizes in such a way that a single probe assembly is capable of examining the test material across a range of perspectives. As a result thereof, during a phased array
scan (Figure # 6), not only the crack position, but also its length, width, depth, etc. can be confirmed from a 2-dimensional image.

**PAUT for detection of Wet H₂S cracking**

Phased Array Ultrasonic Testing (PAUT) was chosen as a solution to the problem of detection of wet H₂S cracking in view of its excellent crack detectivity from the outside surface irrespective of the shape, size and orientation of cracks. The weld joints including HAZ of equipments and the piping of the affected circuits were thoroughly scanned using PAUT (Figure # 7) and cracks could be detected at three more locations. The cracked locations found using PAUT were ground as per procedure after hydrogen bake-out of the area and multiple sub-surface cracks could be observed during the metal removal process. One such area after complete removal of cracks is shown in Figure # 8. The welding of the locations was then carried out as per procedure and were examined using PAUT. The Post Weld Heat Treatment (PWHT) of all repaired welding was carried out to prevent any further cracking issues in future.
Conclusions

The wet H$_2$S cracking of carbon steel equipments remain one of the major causes of in-service catastrophic failures in corrosive circuits of secondary processing units of oil Refineries like Fluidized Catalytic Cracking Units, Hydro cracking and Hydro treating Units. The use of stress relieved equipments in these circuits has greatly reduced the chances of catastrophic failures due to wet H$_2$S. However, in case of process upsets like accidental water carry-over, can render a particular circuit vulnerable to wet H$_2$S corrosion. Hence, the process upset conditions should also be considered during the design and finalization of the process loops requiring protection from wet H$_2$S service. Once there is a chance of wet H$_2$S corrosion in a particular circuit, it is absolutely essential to carry out a comprehensive health assessment of the entire circuit before it can be put back to operation. Traditionally, WFMPI had been the NDT of choice for detection of wet H$_2$S damage. However, the equipments without internal access cannot be assessed by WFMPI. In such cases, the Phased Array Ultrasonic system remains the most convenient NDT method for health assessment. In this case study, PAUT could successfully detect the wet H$_2$S cracks in equipment and piping affected due to accidental ingress of water in H$_2$S bearing streams. This advanced NDT could accurately detect the size, location and orientation of cracks and thus, the repairs could be carried out, thereby increasing the reliability of the equipments.

References

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