

Use of Phased Array Ultrasonic Testing For Sizing of Hydrogen Blisters In LPG Wash Water Vessel In INDMAX Unit

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Abstract - Equipments operating in sour environment containing H₂S are prone to deterioration by wet H₂S damage mechanism. INDMAX unit (patented FCCU) produces LPG which contains H₂S, cyanide as impurities. To remove these impurities LPG is treated with caustic wash and subsequently water wash in series operation. Due to presence of wet H₂S environment in the water wash vessel, nascent hydrogen is produced which diffuses in to the wall of the vessel. Due to presence of laminations in the CS shell these hydrogen atoms combined to form hydrogen molecule which exerts severe internal pressure greater than the yield strength of the CS wall inside the laminations resulting in formation of hydrogen blister. This paper describes the use of phased array UT (PA-UT) technique for detection of lamination and sizing of hydrogen blisters in the LPG wash water vessel. Fitness for purpose study was carried out for safe operation of this vessel.

Keywords - PA-UT, Hydrogen blistering, diffusion, lamination, fitness for service, wet H₂S.

I. INTRODUCTION

The INDMAX Unit of Guwahati Refinery is an indigenously developed technology of Indian Oil Corporation Limited for maximization of LPG production; it is a high severity fluidized catalytic process. LPG from this process unit undergoes various sweetening treatment to remove the H₂S and other impurities present in it. This includes caustic wash treatment and water wash treatment primarily. (Note: H₂S is highly soluble in caustic and water thereby facilitating its separation during caustic and water wash). Due to presence of lamination in the carbon steel shell of the vessel which was subjected to the wet H₂S environment is thus causing hydrogen blistering in the wash water vessel. This paper describes about the inspection programme developed for detection of lamination and sizing of hydrogen blisters in the wash water vessel of INDMAX unit and methodology adopted for its safe operation till its replacement with a new vessel.

II. WET H₂S DAMAGE

The name “wet H₂S” refers to the environment where both liquid water and H₂S are present in the process fluid/ stream. When Carbon steel and low alloy steels are subjected to wet H₂S environment four types of damage can occur in the steel. They are briefly described below:

a) Hydrogen Blistering

The nascent hydrogen atom formed during the sulphide corrosion at the metal surface diffuses inside the metal and collects at discontinuities like inclusion and laminations. This atomic hydrogen combines to form molecular hydrogen which builds up at these discontinuities and exerts localized pressure causing deformation/ blisters. The blisters can form at the inner surface, mid wall or outer surface of the pressure vessel.

b) Hydrogen induced cracking (HIC & SOHIC)

Hydrogen blisters formed in the steel at different depths (planes) develop cracks and interconnect with each other in the form of stair step cracks. That is why HIC is also called “stepwise cracking”. Stress oriented hydrogen induced cracking (SOHIC) is similar to HIC, except that it results in a through-thickness crack that is perpendicular to the surface and is driven by high levels of stress (residual or applied).

c) Hydrogen Embrittlement (HE)

It is the loss of ductility observed in a material under a slow tensile loading. This occurs in materials charged with hydrogen due to exposure in wet H₂S environment over a period of time.

d) *Sulfide stress corrosion cracking (SCC)*

It is defined as cracking of metal under the combined action of tensile stress and corrosion in the presence of water and H₂S. SCC initiates on the surface of steels (generally high strength or high hardness steels) in highly localized zones of high hardness in the weld metal (cover pass/attachment welds) and heat affected zones. PWHT is beneficial in reducing the hardness and residual stresses that render steel susceptible to SCC.

Factors affecting wet H₂S damage:

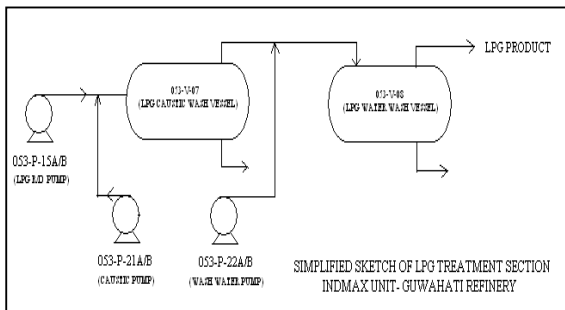
- (a) Environmental factors (pH, H₂S level, temperature, contaminants etc.)
- (b) Material properties (hardness, strength, microstructure)
- (c) Tensile stress level (residual & applied)

Prevention of wet H₂S damage:

- (a) Wash water injection, polysulfide dosing.
- (b) Painting, cement lining, cladding of process side surface to create a barrier.
- (c) HIC-resistant steels can be used to minimize the susceptibility to blistering and HIC damage.
- (d) SCC can be prevented by keeping weld and HAZ hardness below 200BHN. PWHT can be carried out to reduce the stress/ hardness.
- (e) Corrosion inhibitor dosing.

III. PROCESS DESCRIPTION

The LPG treatment facility in INDMAX unit consists of a LPG caustic wash vessel 053-V-07 and a LPG water wash vessel 053-V-08. The LPG is mixed with caustic solution and is sent to LPG caustic wash vessel V-07 through a mixing valve and a static mixer which ensures proper mixing of LPG and caustic. In this vessel the caustic absorbs the sulfur and mercaptans. After caustic wash, LPG is sent to LPG water wash vessel V-08 where service water is pumped by wash water pump through a mixing valve and a static mixer. Water removes traces of caustic from LPG.



Sketch No.1: LPG treatment section of INDMAX Unit.

TABLE I. DESIGN DATA OF THE VESSEL:

Design code	ASME Sec. VIII Div.-1 (1998)
Operating Pressure	17 Kg/cm ²
Design Pressure	19 Kg/cm ²
Operating Temperature	40°C
Design Temperature	70°C
Shell Thickness	18 mm
Dome thickness	18 mm
Corrosion allowance	3 mm
Operating Fluid	LPG + Water
Material for shell & dome	SA 516 Gr 60
Overall size (L x OD)	5915 mm x 1336 mm
PWHT	Full
Capacity	7.48 M3

IV. PHASED ARRAY ULTRASONIC TESTING

Phased-Array Ultrasonic Testing (PA-UT) is an advanced ultrasonic inspection technology for nondestructive testing of critical equipments. Special features of PA-UT are as follows:

- (a) Two kinds of PA Sector scan are conducted simultaneously by two Phased Array Probes.
- (b) Accurate height sizing of each detected flaw can be verified by the applicable VC-sector display (by applying two Tip-Diffraction methods).
- (c) Three dimensional merged displays (B, C & D-Scan) of Dual PA sector scan can be obtained for each scanning unit.

TABLE-II : BENEFITS OF PA-UT OVER CONVENTIONAL UT

Conventional UT	PA-UT
Single element probe	Multi probe array technique
Only defects longitudinal to beam path can be detectable.	Due to angulated beam, defects oriented non parallel to surface are also detectable
Limited facility of recording	Full capability of recording, & reproduction
Electronic steering of Ultrasonic beam is not possible	Ultrasonic beam can be steered with various applied delay to angulated the beam with steering effect, called S- scan

V. OBSERVATIONS

The LPG water wash vessel was opened and black muck was observed inside, which were cleaned manually. On visual inspection it was seen that the vessel had blisters which were found predominantly on the top 50%. These blisters were located with respect to a circumferential seam weld and from the edge of the manhole indicating their sizes as seen from the vessel internal surface. Some of the blisters were seen to have ruptures at their crowns. The height of the blisters was seen to vary between 4mm to 8.5 mm and their diameters varied between 35mm to 130mm. Cracks up to 50 mm length were observed at almost all the blisters. Most of the cracks were branched in different directions. The thickness of the bulged portion from inside was observed between 7 to 9 mm. Grooving up to 1 mm depth were also observed at distributed locations at the top half of the vessel. However, no blisters were observed at both the domes and the bottom half of the shell of the vessel.

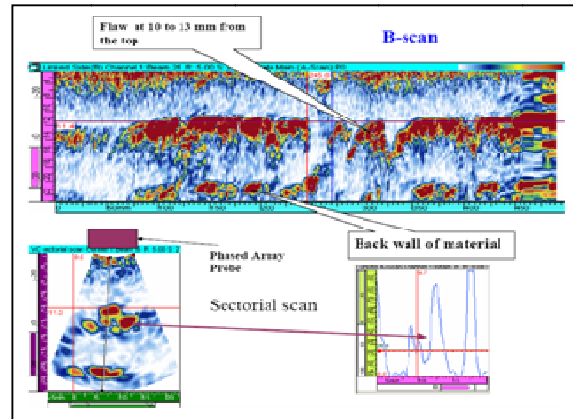


Photograph No.01: Series of blisters on the shell.



Photograph No.02: Close up view of a blister with branched cracks at its center.

Phased array ultrasonic testing was carried out for determination of actual region of damage and for sizing of the defects. Ultrasonic B-Scan was used to find the distance between two individual indications in x-direction where as sectorial scan (S-Scan) was used to find out axial indications. 3D mapping of vessel using multichannel PA-UT revealed linear indications varying in size from a minimum of 4mm to 25mm at a depth varying within 10 to 13mm from outside surface. PA-UT also confirmed that the extent of damage is predominantly on the top half of the vessel as compared to that of the bottom.



Photograph No.03: Section view of vessel shell plate showing blisters in the mid-wall section under PA-UT scan.

VI. ENGINEERING CRITICAL ASSESSMENT

Considering the criticality of service, the vessel has been analyzed through Engineering Critical Assessment approach using RLA software. In this analysis the following steps were followed:

A. Defect interaction analysis

The blisters have been considered as embedded defects at mid thickness of 9mm from the internal surface. The interaction effects of blisters in line along the vessel axis were checked and the equivalent defect sizes were obtained. After interaction analysis, three numbers of defects resulting from interaction effect and three more defects, which were individually large in size and located nearer to weldment, were selected for fitness assessment.

B. Stress analysis at defects

The stress analysis module of the RLA software was utilized in evaluation of stress in the vicinity of the critical defects identified. The analysis was carried out with contributing factors such as: operating pressure of 17 and 13 kg/cm², presence of 20" manhole, presence of saddle supports and self weight of the vessel. The

analysis revealed that the presence of manhole opening had only a marginal effect on the stresses at the critical defects.

C. Integrity analysis

Fitness for service assessment in presence of the identified critical defects was made using the actual material properties as reported in the material test certificates and the lowest reported fracture toughness for A 516 Gr60 material. The analysis has been performed with variations on the operating pressure of 17 and 13 kg/cm², service gradation as critical, reliable/less reliable defect size estimation, weld residual stresses and bending stress due to saddle support.

D. Minimum thickness for pressure containment

The minimum thickness required for simple pressure containment has been evaluated using allowable stresses as per ASME Section VIII Division-I, based on the actual minimum strength requirement of the material specification as well as actual value from the material test certificate. The values are tabulated in table-III. Formula used for minimum thickness calculation is

$$T = \frac{P \cdot D}{2 \cdot S \cdot E} \dots\dots\dots [7]$$

Where,

T = Minimum thickness required (mm)

P = Operating pressure (kg/cm²)

S = Elastic allowable stress as per ASME
(144 Mpa, 15% of UTS)

E = Joint efficiency (1)

TABLE-III. MINIMUM THICKNESS CALACULATION RESULTS

Operating Pressure	Minimum Thickness required	
	As per Min. specified in ASTM A516 Gr60	As per original MTC
17 kg/cm ²	12 mm	10.442 mm
13 kg/cm ²	9.36 mm	7.98 mm
11.5 kg/cm ²	8.28 mm	7.06 mm

VII.DISCUSSION

From process parameters study, history of the equipment, nature of defects etc. it is inferred that the root cause of blister formation within short service of the vessel is on account of H₂S slippage resulting from insufficient caustic wash of LPG. The hydrogen liberated in the presence of wet H₂S facilitates diffusion

of nascent hydrogen in the metal. This hydrogen recombines at regions of heterogeneities/ discontinuities (laminations) within the material. The consequent localized increase in presence at these locations results in blisters. Presence of cyanides (normally formed in INDMAX/ FCCU) further accentuates the hydrogen diffusion into the material.

PA-UT analysis reveals that most of the linear indications lie embedded near mid wall with a remnant thickness of minimum 10 mm from the outer surface.

The Engineering Critical Assessment of some of the critical defects identified reveals acceptability of all defects when the vessel is operated at a maximum pressure of 13 kg/cm².

The minimum thickness calculations also revealed presence of adequate thickness when operated at a maximum pressure of 13 kg/cm² as compared to the remnant thickness reported in non destructive tests.

VIII.RECOMMENDATION

The condition of the vessel has deteriorated considerably and it was recommended for replacement with a new vessel internally lined with refractory within three months.

The vessel was continued to be used for a few months till arrival and installation of the new vessel under the following operating conditions:

- (a) The vessel was re-rated for a maximum operating pressure of 13 Kg/cm².
- (b) In case the operating pressure is further reduced from 13 kg/cm², it is to be ensured that same doesn't cause formation of LPG vapor in the wash water vessel.
- (c) All blisters were punctured by drilling on their crown. Hand drills were used for this purpose with adequate precautions for safety of the personnel. This precaution was required as a safe guard against accidental burning of hydrogen released by the blisters.
- (d) The PSV mounted on the vessel was set at 12.7 Kg/cm² as against the original of 19 Kg/cm², so during operation the pressure does not exceed the re-rated value.
- (e) Hydro test of the vessel was avoided to prevent unnecessary stresses being generated.

IX. CONCLUSION

To avoid such problem in the wash water vessels in any FCCU the following points must be taken care of during the manufacturing and operation of such vessels:

- (a) The plate materials should be ultrasonically tested prior to fabrication as per ASME/ ASTM specifications to rule out the presence of defects like laminations/ inclusions in the plate.
- (b) The efficiency of the reaction between caustic and LPG should be increased so that sufficient resident time will be available for the reaction to be completed. This can be achieved by installation of an efficient continuous film contactor.
- (c) During fabrication stage all vessels in similar service shall be given PWHT irrespective of code requirements. This may be included in the customers engineering/ standard specifications over and above the governing code requirements.

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