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Circular Economy Opportunity Utilizing Fitness for Service Methodology for Aged HIC Defected Reboiler

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Abstract:- The phenomenon of Hydrogen-Induced Cracking (HIC) is a cracking mechanism of carbon steel material as in ASME SA- 516 pressure containing equipment operating in a wet sour H2S environment. Such phenomenon is mainly driven by the diffusion of hydrogen atoms into the carbon steel due to corrosion reaction. The Structural integrity of an in-service equipment that contain a flaw or damage such as HIC could be scrutinised using Fitness For Service (FFS) assessments as quantitative engineering evaluations. The assessments are conducted using methodologies specifically prepared for pressurized equipment. These assessments provide standard procedure that can be used to determine if pressurized equipment containing flaws could continue to operate safely for certain period of time. FFS assessments are recognized and referenced by the API Codes and Standards such as API-510, 570, & 653, and by National Board-23. Those assessments are considered suitable methodologies for evaluating the structural integrity of pressurized equipment as heat exchangers, pressure vessels, piping systems and storage tanks where inspection has revealed degradation and flaws in the equipment. The objective of this paper is to illustrate API-579 case study of HIC of fifty (50) years operating pressurized equipment, namely reboiler.

I. INTRODUCTION

Pressurized equipment running in oil and gas industry such as heat exchangers, pressure vessels and pipelines that contain H2S services might cause significant risks to operating facilities' personnel and the surrounding environment in case of equipment failures. Therefore, it is mandatory to ensure that the pressurized equipment materials made of carbon steels used in wet sour H2S services are compatible and resistant to hydrogen-induced cracking (HIC) and sulfide stress corrosion cracking (SSC) phenomena. Defected equipment, such as HIC, cracked and corroded pressurized equipment shall be evaluated using fitness for service assessments to ensure they fit to operate safely and reliably during the upcoming operation cycle. Therefore, international standards as API-579 was developed to provide methodologies for assessing fitness for service of damaged equipment. The assessment procedure is intended to evaluate the remaining strength of the defected equipment in its current operating condition and provides measures and recommendation actions for repair or replacement. API-579 covers three (3) levels of assessment in which Level 1 and Level 2 are performed by operating facilities. They require minimum amount of maintenance and inspection records and known to be conservative. However, Level 3 assessment requires more detailed inspection and Finite Element Analysis (FEA) method to give in-depth analysis. Level 3 assessment usually are performed when both Level 1 and Level 2 are failed to verify the equipment conditions.

II. FITNESS FOR SERVICE STANDARDS

➢ *FFS Assessment Procedures are Typically Developed by Recognized Standards and Methodologies, Such as:*

- API-579-1/ASME FFS-1 which is a comprehensive standard developed jointly by the American Petroleum Institute (API) and the American Society of Mechanical Engineers (ASME). This document provides procedures for conducting FFS evaluations, including assessment of flaws, analysis of damage mechanisms, and methods for establishing allowable limits for continued operation.
- BS-7910 is a British Standard developed to provide well-structured procedure for assessing existing flaws in operating pressurized equipment and verify their acceptability in metallic structures.

III. FFS ASSESSMENT LEVELS

➢ *Based on the Proven Industry Procedures, there are three (3) Different Levels of FFS Assessments as Follows:*

- Level 1 FFS assessments which is considered the simplified assessment and conservative compared to other. Level 1 provides screening criteria based on the least amount of maintenance and inspection records and equipment mechanical information. Extensive detailed calculation is not required for Level 1 assessments in which such assessments could be performed by operating facility engineers.

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- Level 2 FFS assessments which is classified as normal assessment and involves a more detailed evaluation of components compared to Level 1. It usually requires an accurate measurement of flaws or damage dimensions. Level 2 FFS assessments resulted in the required component thickness or of component stress. Such assessments are usually performed by Engineering specialists.
- Level 3 FFS assessments which is classified as ductile tearing instability. Such level assessments require detailed evaluation of defected equipment or components. Pressurized component flaws or damage must be accurately determined, and calculation methods often involve numerical analysis such as the finite element method. Level 3 assessments are conducted by experts based on equipment design data, equipment operation conditions, FEA and fracture mechanics.

IV. FFS EVALUATION METHODOLOGY

FFS evaluations are crucial for industries where equipment failure could result in significant safety hazards, environmental incidents, or economic losses. The FFS evaluation process typically involves the following steps:

- Data Collection and Documentation: Gathering all necessary data related to the equipment, including design specifications, operating conditions, inspection history, maintenance records, and any available information about the identified damage or degradation.
- Damage Mechanism Identification: Determining the type(s) of damage mechanisms present and understanding their impact on the integrity of the equipment.
- Assessment Techniques: Selecting and applying appropriate analytical methods and techniques to assess the integrity of the equipment. This can include numerical simulations, fracture mechanics analysis, remaining life calculations, and other engineering evaluations.
- Acceptance Criteria: Establishing acceptance criteria based on industry standards, regulatory requirements, or custom engineering judgments to determine whether the equipment can continue to operate safely.
- Remaining Life Estimation: Estimating the remaining useful life of the equipment, considering the current condition and the projected evolution of the damage.
- Recommendations and Reporting: Making recommendations regarding the continued use, monitoring, maintenance, repair, or replacement of the equipment and documenting the findings in a report.
- Implementation of Recommendations: Based on the FFS report, implementing any necessary actions to ensure the continued fitness for service of the equipment.

V. REQUIRED DATA FOR FFS ASSESSMENTS

To perfume comprehensive and complete FFS assessments, equipment and failure records are required. Those data depend on the flaw type and damage mechanism being evaluated. Data requirements shall include as minimum requirements: as-built original equipment drawings & design data, maintenance and operational history, expected future service, and data specific to the FFS assessment such as flaw size, state of stress in the component at the location of the flaw, and material properties.

➢ *The Common Use of FFS Procedure is Applicable to Four (4) Major Stages of a Typical Component Life:*

- Design of New Structures
- Fabrication Support and Quality Assurance
- Assessment of In-Service Damage
- Failure Analysis

➢ *Moreover, Typical Applications Of FFS Assessments are Usually Including:*

- Periodical structural verifications of flaws due to metal loss of pressurized components, crack detected in-service on welding stressed under fatigue conditions, extended operating of process fired heaters and boilers working in high temperature.
- Upgrading of existing operating facilities free of periodic flaw checks.

VI. CASE STUDY: HIC OF 50 YEARS CARBON STEEL REBOILER

This case is one of the oldest operating reboilers with HIC defects. The reboiler is running for almost 50 years. The defect details are shown in below inspection table. The following is the equipment operating and construction data.

- Material: CS A-515 Gr.65 ID: 2286 mm (90 inches)
- Design Condition: 2.06MPa (300 psi) & 188 ˚C (370 ˚F) Weld Joint Efficiency: 1
- Year of construction: 1974

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Table 1: Inspection Data

	Indication #	X-Position	Y-Position	Min. Depth	Max. Height	Defect Type
Scan # 1	1	106	206	10.6	4.9	HIC
	2	274	304	21.2	2.3	HIC
	3	268	404	19.4	3.4	HIC
	4	98	422	18.7	3.5	HIC
	5	80	330	14.6	-	Blister
* All dimension in (mm)	6	184	358	19.7	-	Blister
	7	226	322	18.8	3	HIC

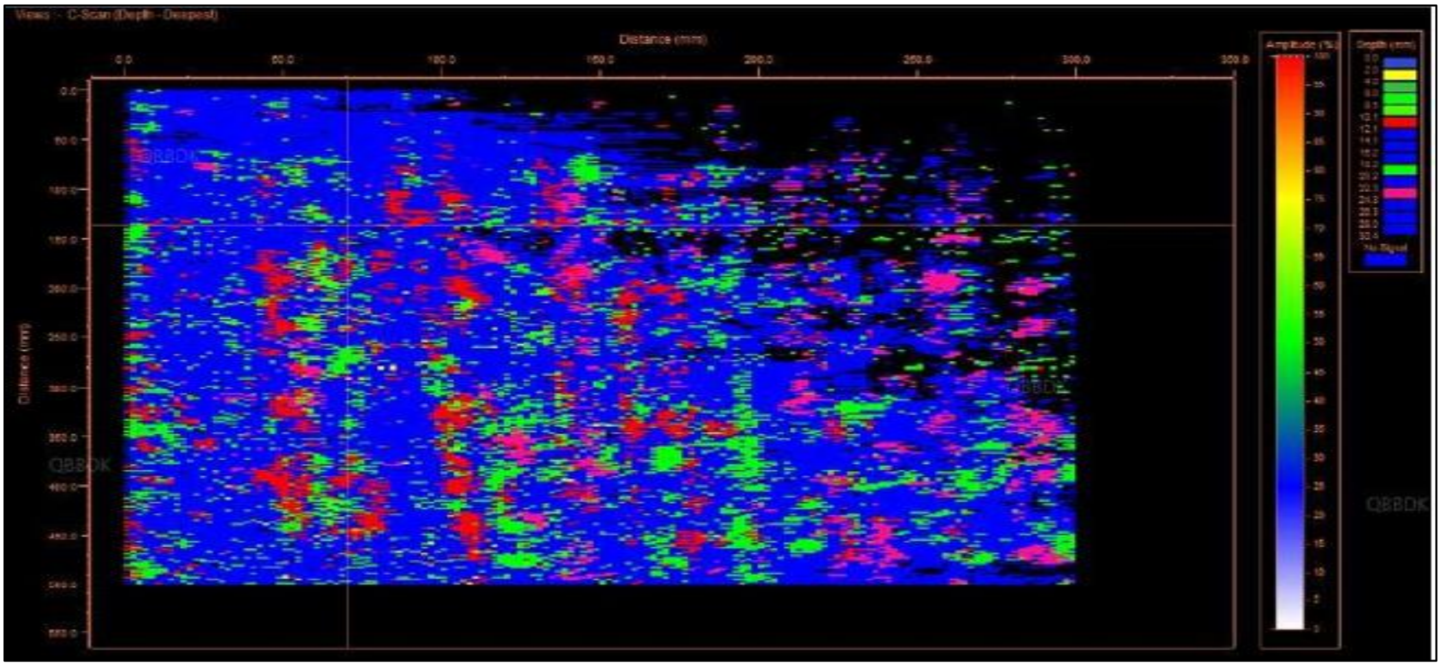

Fig 1: General View of Indication-1

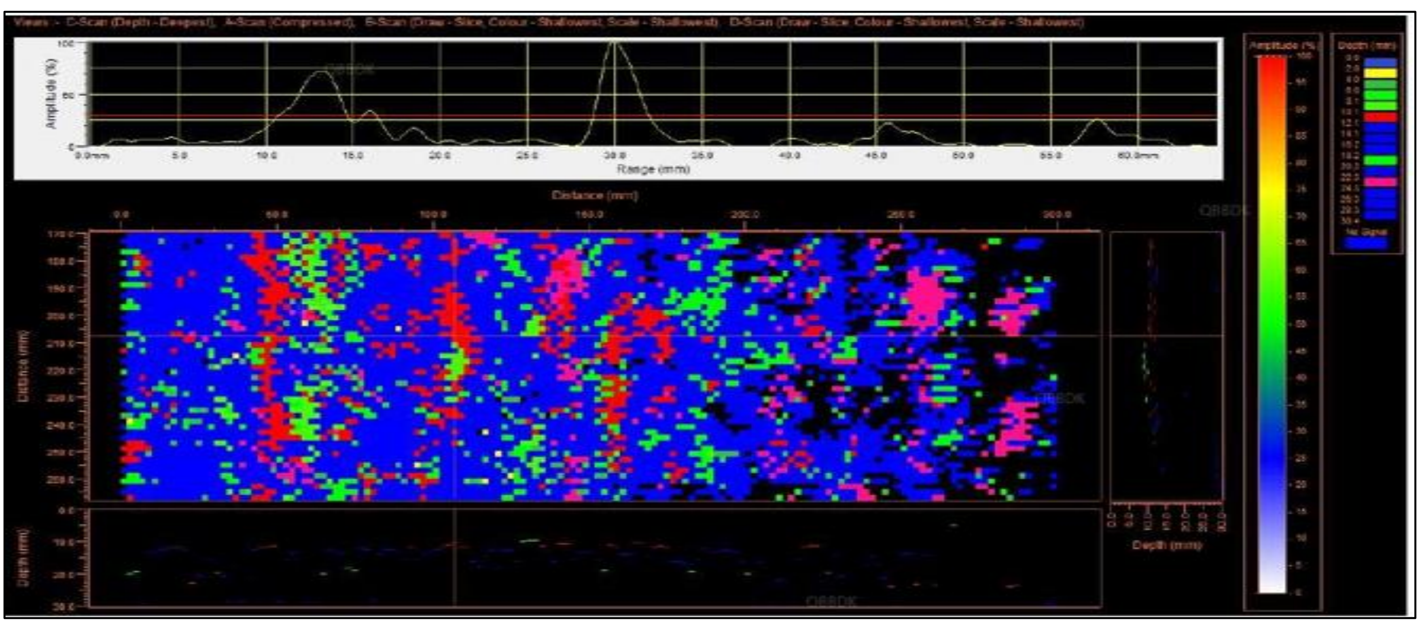

Fig 2: Close-up View of Indication-1

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VII. ANALYSIS RESULTS & RECOMMENDATION

Based on the analysis results shown in Table-2, the reboiler fits for service following API-579 level-2 criteria.

Due to the criticality of the sour service equipment with HIC cracks, it is recommended to maintain regular inspections of the reboiler to measure the crack size to reassess the reboiler conditions during the upcoming opportunity. Additionally, reduce the rate of hydrogen ingress from the environment into the material by applying protective coating will help to minimize the crack growth.

Table 2: Analysis Results

	Input Data:					
	Plant	ABC		Equipment	ABC-E-224 (1974)	
	Date				10/20/2022	
	t	28	[mm]	Actual reported thickness		
	FCA	1	[mm]	Future rate for 5 years		
	t_OD	10.6	[mm]	Crack depth		
	W_h	4.9	[mm]	Crack height		
	S	111.70	[Mpa]	Allowable stress		
	E	1				
	Di	2286	[mm]	Inside diameter		
	R	1143	[mm]	Inside radius		
	P	2.06842	[MPa]	Design Pressure		
	s	900	[mm]			
	c	300	[mm]			
	L_w	500	[mm]			
	L_msd	550	[mm]			
	L_H	150	[mm]			
	L_Hs	150	[mm]			
	Calculation:					
	tc	27	[mm]			
	t_ID	11.5	[mm]	Thicknesses are OK		
	0.2*tc	5.4	[mm]			
	t_OD ≥ 0.2*tc	OK				
	t_ID ≥ 0.2*tc	OK				
	HIC is	Sub-Surface				
	8*tc	216	[mm]			
	L_H ≥ 8*tc			Merge the two cracks		
	Output Data:					
RESULTS		FFS Assessment are conducted per Level 2				
	MAWP=	2.53	[MPa]	2016 Edition	1.447896	[MPa]
		367.08	[psi]		210	[psi]
	No need for Re-rating					
					By: Dhawi Al-Otaibi	

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VIII. CONCLUSION

The reboiler underwent a Level 2 FFS assessment. Given the substantial presence of hydrogen-induced cracking (HIC), the equipment was returned to service with control measures and without the need for re-rating.

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