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Risk Based Inspection of Composite Components in Oil and Gas Industry

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ABSTRACT

The aim of technical inspection activities is to ensure all components are working in a safe condition. Approaches in technical inspection turn to cost effective and much reliable strategies such as inspections based on the level of the risk of the components. Risk based inspection (RBI) is the process of developing a scheme of inspection based on knowledge of the risk of failure. RBI procedure is the combination of an assessment of the probability of failure due to flaws damage, deterioration or degradation in conjunction with an assessment of the consequences of such failures. RBI helps to increase the safety of the processing unit, reduce the costs, and improve environmental protection. Now the RBI procedure is the core of many inspection strategies in the oil and gas industry. However, the application of RBI in non-metallic components is rarely studied. In this paper, the risk assessment of the GRE/GRP components is investigated. Composite components are extensively using in water (includes deposit water, waste water, and wash water) systems. Through this study, different failure mechanisms in composite components are discussed. The results of RBI method indicated that composite components should be inspected within the second year after the start of the service. Because of the low and medium overall risk of the components, a visual inspection shall be performed in three/five years' duration for non-metallic piping and tanks.

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1. Introduction

Technical inspection of critical equipment such as pipes, reactors, pressure vessels, tank boilers, etc. is of key importance for safety assurance in large-scale processing facilities in the oil, gas, and petrochemical industries. Risk Based Inspection is considered as one of the most attractive inspection strategies in large units. The main goal of technical inspection methods is to ensure the mechanical integrity of the facility.

To ensure mechanical integrity, all critical components shall be inspected at the intervals subscribed by rule based methods or as per risk-based inspection (RBI) methodology. The later may allow previously established inspection intervals to be extended and hence, can add the economy of the company [1].

The main objective of RBI is to determine what incident could occur (consequence) in the event of an equipment failure, and how likely (probability) is it that the incident could happen [2].

Risk-based inspection methodology provides quantitative, semi-quantitative or qualitative procedures to establish integrity plans for pressurized fixed equipment including pressure vessel, piping, tankage, pressure relief devices (PRDs), and heat exchanger tube bundles. One of the typical RBI methodologies was proposed by the consortium of American Petroleum Institute (API) and oil companies and published as API 580/581, which has been used to various industries including an oil refinery, petrochemical, gas, chemical industries [2-4]. RBI method has been successfully applied to equipment working in different conditions such as in marine pipelines [5], sweet and sour gas piping systems [6], and for different materials of constructions such as fiberglass reinforced polymer storage tanks [7].

Among all equipment in the oil and gas industry, both the steel or non-metallic storage tanks have extensive applications in storing the oil, petroleum, fuel, kerosene, water, and other fluids. Depend on the material of construction, and the service fluid, a wide range of damage mechanisms can be a source of storage tank deterioration and degradation. But the prevalent mechanisms are corrosion, erosion, creep, fatigue, chemical attack, mechanical damage, and brittle fracture [8].

Generally, storage tanks can be cylindrical and spherical. Spherical storage tanks primarily consist of the lower support structures and the spherical shell structures, which sit on support structures. Specifically, the shape of the shells can be spherical, elliptical, and teardrop-shaped, among which spherical tanks are the most widely used as for the same volume and thickness, spherical tanks use the minimum amount of steel and cover a minimum area [9]. Vessels and storage tanks in the petrochemical industry commonly are made of steel, concrete or non-metallic materials such as Glass Reinforced Epoxy (GRE) and Glass Reinforced Plastics (GRP).

Shuai et al. [10] applied RBI methodology for the risk assessment of large scale crude oil tanks in order to determine the acceptable risk and internal inspection interval of the steel tanks. The risk associated with each tank was calculated at a time when the bottom plate thickness reaches the minimum required thickness, and the minimum calculated value was used as the risk target. This research showed and the capability of the RBI method to identify the problems that may lead to future loss of integrity and also can provide the information of deterioration state of tank plates and reduce risk uncertainty of crude oil tank.

Trebuna et al. [11] studied the failure analysis of the steel storage tank for hot water. Low alloy steel has been widely used in oil and water storage tanks due to its strength and durability. However it is very susceptible to corrosion when used in high temperature and high humidity environments [12]. Glass Reinforced Plastic (GRP) is seen as an attractive alternative material to low alloy steel, mainly due to its high corrosion resistance in extreme conditions and low cost. Compared to steel, GRP also offers reduced maintenance costs and ease of handling due to its low weight, high strength-to-weight ratio, good resistance to bacterial growth, reduced risk of osmotic attack and production cycle time [12].

Nowadays, there has been an increased trend in the use of non-metallic materials for making tanks and pipes used in low pressure oil processes. Non-metallic pipes and tanks can be classified into three major categories; thermoplastic materials, fiber-reinforced materials, and cement asbestos.

Corrosion is one of the most important problems factor influencing drinking water quality that causes health disorders and economic problems in the drinking water industry [14]. Having high corrosion resistance properties in GRP/GRE materials make them exceptional material for using in water (deposit, waste [13] and drinking [14] water) storage systems.

Cracks and other corrosion induced failure mechanisms can lead to the collapse of the GRE/GRP structure [15]. Despite the wide usage of plastic tanks in petrochemical industries, rare studies dedicated to the integrity of these types of tanks. Foulon et al. [15] studied the applicability of the acoustic emission method in the in-service evaluation of the mechanical integrity of GRP equipment. Indeed, the application of RBI in non-metallic components is less studied. In this paper, the risk assessment of the GRE/GRP tanks is investigated. It is well known that the RBI methodology presented by the American Petroleum Institute as API-RP-580/581 standard [3, 4] does not cover the risk assessment of the polymeric materials. Therefore, in the present study the usability of the explained RBI methodology was investigated in GRE/GRP storage tanks based on Norwegian Oil and Gas Recommended Guidelines for NDT of glass fiber reinforced plastics (GRP) Pipe Systems and Tanks [16], as well as the NORSOK STANDARD for Fabrication and installation of GRP piping systems [17].

2. Damage Mechanism

Determination of reliable damage mechanisms is the first step in defining failure scenarios or risk scenarios. Damage mechanism in GRE/GRP components normally depend on materials of construction for the containment (e.g. storage tank), severity of manufacturing procedures, weather conditions at time of construction and installation, operating temperature, composition of contained fluids (e.g. concentration of chemicals and deposits of service fluid), and presence of contaminants especially in wastewater (such as ammonia, cyanide, salts of hydrochloric acid and sulfuric acid, thiocyanates and other organic solvents).

Corrosion and subsequent failure, particularly on storage tanks bottom plates, is one of the main factors upsetting any upstream/downstream production facilities. In the upstream industries, operating temperature rates for water (deposit, waste and drinking water) storage systems can be (-4 -60), in this temperature range and the fluid composition, active damage mechanisms are the same for all deposit, waste and drinking water for the plastic material of construction.

Based on Norwegian Oil and Gas Recommended Guidelines for NDT of GRP Pipe Systems and Tanks [16], the damage mechanisms in polymeric components can be adapted as following:

- Mechanical cracking (bolts over-torqued, GRP against raised-face flanges, wrong GRP flange design selection);
- Transport and handling damages (impact or wear);
- Manufacturing defects (incorrect curing, Incorrect lay-up in lamination, voids, outside temperature and humidity specs., improper

mixing, improper treatment of joint adherents, overlap or controller problems, cooling effect of air in the pipe, out of date or incorrect materials, movement during curing, bending, incorrect dimensions, Excess adhesive/cavitation);

- Improper maintenance activities (exceeding bolt torque, exceeding design loads, etc.);
- Embrittlement and corrosion cracking (HCl acid attack; the acid will attack the resin surface, but it also penetrates to glass fibers, especially when the HCl is concentrated and/or hot. Moderate to light attack can be characterized by surface crazing and micro cracking. The more pronounced attack will show clearly defined cracks.)

For detection of these defects using of the Non-Destructive Testing (NDT) techniques (such as visual inspection, pressure test, acoustic emission, ultrasonic, radiography, thermography, etc.) are recommended.

3. Probability of Failure (POF)

The probability analysis in an RBI program is performed to estimate the probability of a specific adverse consequence resulting from a loss of containment that occurs due to damage mechanisms. The probability of Failure (POF) in polymeric materials varies for different damage mechanisms and depends on many manufacturing and operating factors. The followings are the most important factors affecting the POF in polymeric components.

- Operating temperature
- Presence of organic solvents
- Presence of abrasive solids
- Inspection history indicating the prior history of veil degradation with known regions of veil loss or past repairs
- Inspection history indicating the regions with cracks into the structural layers
- History of thermal shock
- Acceptable acoustic Emission test within the last 5 years
- Internal inspection shows no surface cracks (normally expected darkening due to oxidation can be waived).

Table 1, demonstrates possibility categories for polymeric components.

Table 1. Probability Categories for Polymeric components

Probability Category	Range of Probability over Time Frame	Description
A- Very Likely	>=0.1 to <1.0	Very likely occurrence over the time-frame for this facility
B- Likely	>=0.01 to <0.1	likely occurrence over the timeframe for this facility
C- Possible	>=0.001 to <0.01	Infrequent occurrence over timeframe for this facility
D- Unlikely	>=0.0001 to <0.001	rare occurrence over timeframe for this facility
E- Very unlikely	<= 0.0001	Rare occurrence over timeframe industry wide

4. Consequence of Failure (COF)

The COF analysis performs to estimate the consequences that occur due to a failure mode typically resulting from an identified damage mechanism. Once a damage mechanism and the associated probability of occurrence are identified, the consequences of failure are determined. The most important failure consequences in the polymeric storage systems are "health and safety", "environmental" and "Economic" outcomes.

Health and safety consequences express based on the severity of an injury (e.g. fatality, serious injury, medical treatment, first aid) or express as a category linked to the injury severity. The economic consequence categories include the cost of lost production, replacement, repair costs, or other consequential costs that might result from the failure (such as a major disruption leading to market share loss).

The consequence of failure extremely depends on fluid service characteristics. If the fluid service to be H_2SO_4 , micro cracks will lead to damage of the glass fiber and structural failure from the tank shell or piping to occur. A large release of H_2SO_4 and severe damage to surrounding equipment is expected. However, for drain water fluid service, especially in low operating pressure and inventory masses, neither significant environmental nor economic consequences are not expected.

5. Final Risk

Probabilities and consequences of Failure are combined to determine a total risk over the plan period being considered. In the risk assessment of polymeric components, the risk matrix was identical with the risk matrix in API 581 recommended practice [3]. Figure 1 demonstrates the risk matrix, which was benefited in this study.

6. System Description

The non-metallic unit which is studied in this study includes four piping systems and one storage tank. All piping made of GRE material and their operating pressure is one bar. The fluid service for all piping and tank have the same corrosive severity. Table 2, presents the summary of the analysis for the drain water of the unit. All piping separated into two corrosion loops and the vessel also assigned a different corrosion loop number based on their corrosion behavior and the operating condition. Table 3 indicates the design and operating conditions for the components under study.

Table 2. Summary of drain water analysis

Overall	Component	Molar Fraction
	Nitrogen	0.000008
	CO2	0.000086
	H2S	0.000002
	Methane	0.000731
	Ethane	0.000232
	Propane	0.000336
	H2O	0.99243
Vapor		
	Nitrogen	0.007421
	CO2	0.050970
	H2S	0.000474
	Methane	0.496849
	H2O	0.006847
Light Liquid		
	Nitrogen	0.000014
	CO2	0.000673
	H2S	0.000024
	H2O	0.000171
Heavy Liquid		
	Nitrogen	0.000000
	CO_2	0.000032
	H_2S	0.000006
	H_2O	0.999911

Table 3. Polymeric components' pre-assessment data

Corrosion Loop No.	1- Type	2-System Description	3-Equipment Buried (Yes/No)	4-Size External Diameter (Inches)
D-GRE-01	Pipe	DRAINS (GENERAL)	YES	3
D-GRE-01	Pipe	DRAINS (GENERAL)	YES	4
W-GRE-02	Pipe	WASH WATER	YES	3
D-GRE-01	Pipe	DRAINS (GENERAL)	YES	4
DW-CS-03	Vessel	DISTILLED WATER	No	65

Table 3. Polymeric components' pre-assessment data (Cont'd)

Corrosion Loop No.	5-Design Pressure (Bar)	6-Design Temperature (Degree C)	7-Primary Fluid Phase	8-H2SO4 Exists	9-HCl Exist	10- FLUID DENSITY KG/ M3
D-GRE-01	7	85	Liquid	No	No	1000
D-GRE-01	7	85	Liquid	No	No	306-789
W-GRE-02	17.8	65	Liquid	NO	NO	1000
D-GRE-01	7	85	Liquid	NO	NO	306-789
DW-CS-03	1	85	Liquid	NO	NO	995.6

7. Results and Discussions

Qualitative RBI analysis is performed for the components listed in Table 3. In the calculation of the POF, the chance of occurrence of each type of damage mechanism mentioned in section 2 are considered and the weighted sum of the POF for each damage mechanism result the final POF for each component. As the fluid service is non-flammable and its toxic effect is low, the environmental side effects of the fluid release play a key role in the determination of the COF of the components. Then, the fluid inventory and fluid composition are the main parameters in the qualitative evaluation of the COFs for components. The results of the evaluation for all three corrosion loops are presented in Table 4. As it is obvious from Table 4, the consequences for corrosion loop one (D-GRE-01) is the highest among all, as its inventory volume is the highest. Furthermore, the proposed inspection plan for these types of components are offered for each loop in Table 4.

Table 4. Overall Risk and Inspection Plan of the Polymeric components

Corrosion Loop No.	1- Material	2- POF Category (1-5)	3- COF Category (1-5 or A-E)	4- Overall Risk	5- Integrity Management Plan (Inspection Interval and plan)
D-GRE-01	GRE	2	C	Medium	Visual Inspection including depth gages, penetrants. Not > 3 years
W-GRE-02	GRE	2	B	Low	Visual Inspection including depth gages, penetrants. Not > 5 years
DW-CS-03	GRP	1	B	Low	Internal Visual Inspection focusing on Nozzle, shell, bottom transition regions and other areas of stress concentration, inspect for areas of high fluid velocities for the accelerated attack, Assess crack penetration into structural layer. Repair/ patch areas of attack and install wear plates as appreciate. Not > 5 years

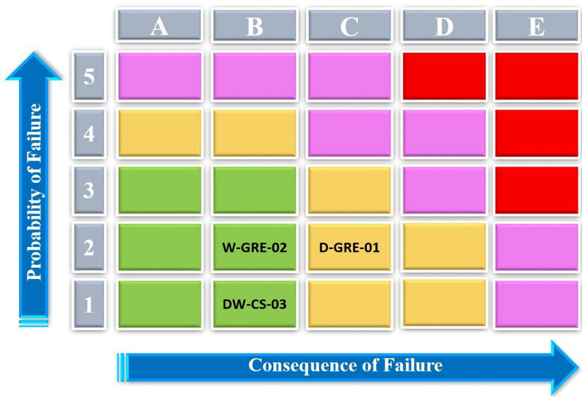

Figure 1. Risk Matrix which is used in this study

8. Conclusion

In this paper, the risk based inspection of the non-metallic components are described with an example of a small unit. Damage mechanisms for this type of components are listed and their probability of failure are discussed. According to the standard procedures, as the fluid service is drain or wash water, the environmental effect of the failure is much important than safety and cost criteria. Hence, the inventory volume is the much important factor in determination of the consequence of failure of the component. Based on obtained results the inspection plan for the investigated corrosion loops are proposed.

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بازرسی بر مبنای ریسک اجزای کامپوزیتی در صنایع نفت و گاز

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چکیـــــــده

هدف از فعالیت های بازرسی فنی اطمینان از کارکرد اجزاء در شرایط ایمن است. در حال حاضر، رویکرد اصلی در بخش بازرسی فنی حرکت به سمت راهبردهای بازرسی با صرفه اقتصادی و نیز قابلیت اطمینان بالا است. بازرسی بر مبنای ریسک (RBI) فرایند ایجاد برنامه بازرسی بر اساس دانشی است که از ریسک خرابی تجهیز بدست می آید. بطور کلی روش RBI مبتنی بر ترکیب دو عنصر احتمال خرابی در نتیجه آسیب، کاهش کارایی و یا تخریب تجهیز و پیامدهای چنین خرابی ها است. RBI به افزایش ایمنی واحد و کارخانه کمک کرده، هزینه ها را کاهش و حفاظت از محیط زیست را بهبود می بخشد. هم اکنون روش RBI به عنوان بخش مرکزی بسیاری از استراتژی های بازرسی در صنعت نفت و گاز ارزیابی می شود. با این حال، استفاده از RBI در اجزای غیر فلزی کمتر مورد مطالعه قرار گرفته شده است. لذا در این مقاله، به ارزیابی ریسک اجزای GRE/GRP پرداخته شده است. اجزای کامپوزیتی به طور گسترده در سیستم های انتقال و ذخیره آب (شامل پساب ، فاضلاب و آب شستشو) استفاده می شود. در این مطالعه، مکانیزم های مختلف خرابی در اجزای کامپوزیتی مورد بحث قرار گرفته شد. نتایج ارزیابی TEM نشان داد که اجزای کامپوزیتی این مطالعه بایستی در سال دوم پس از شروع بهره برداری مورد بازرسی قرار گیرند. از آنجا که بر اساس ارزیابی صورت پذیرفته متوسط ریسک کلی اجزا کم است، بنابراین بازرسی چشمی برای دوره های سه الی پنج ساله برای لوله ها و مخازن غیر فلزی این مطالعه پیشنهاد شده است. .

واژگان کلیدی: بازرسی فنی، مخازن **GRE/GRP**، بازرسی بر مبنای ریسک، خوردگی.