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Original Article

Remaining Life Assessment and Corrosion Rate on Storage Tank Using ASME/FFS-1 A 579

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Abstract *- A Storage Tank is an important piece of equipment for oil exploration and exploitation that functions as a large amount of fluid storage. Storage Tanks are very susceptible to corrosion because the material used in making this Storage Tank is made of steel. Therefore, the Indonesian government applies a regulation regarding the determination of the remaining service life of equipment listed in Ministerial Regulation No. 32 of 2021; it is necessary for Residual Life Assessment (RLA) to prevent holes and structural failures of the tank. The method used is the Visual Examination of UT Thickness. Then the thickness value is used to analyze and calculate the required thickness (Treq), Corrosion Rate (CR), Maximum Filled Height (MFH) and the remaining life (Remaining Life) of the Storage Tank. The results of the RLA found that the remaining service life of the Storage Tank was 20 years with a corrosion rate of 0.034 mm/year, while the UT thickness measurement found the lowest component value on the roof section of 5.76 mm. No significant anomalies were found during the inspection, which might affect the storage tank's ability to continue operations safely. However, it is recommended to maintain the condition of the storage tank so that it remains in its service function.*

Keywords *- Carbon Steel, Corrosion, Material, Residual life assessment, Storage tank.*

1. Introduction

In the oil and gas industry sector, especially in offshore infrastructure, which is more prone to corrosion, efforts to prevent and mitigate corrosion attacks are a priority. Approximately 70-80% of the material used in offshore oil and gas production facilities is made of carbon steel prone to corrosion. Apart from the possible dangers to the platform structure, a corrosion attack is also possible in several other ways (1).

Safety is a crucial aspect of oil and gas exploration and exploitation operations. Because it is related to asset safety, environmental safety, and human resource safety. (2)

Storage Tanks are essential equipment in oil exploration and exploitation that function as fluid storage in large quantities. Storage Tanks are very susceptible to corrosion because the material used in the manufacture of Storage Tanks is steel. (3)

Storage Tanks only identify one type of equipment in an industrial facility. Tanks have been used in many ways to store every liquid, vapor, and, in some processing applications.

Corrosion is a chemical or electrochemical reaction process with its environment. The corrosion process is accelerated by external factors, including the tank's interaction with interconnected components, corrosive environmental conditions, and stray electric currents. (4)

Over time, uncontrolled corrosion can weaken or destroy components of the tank system. This condition is likely to result in a hole or possibly a structural failure of the tank. As a result of the failure of the tank causes the release of stored products into the environment and causes material and life losses. (3)

Therefore, the Indonesian government applies a regulation to determine the remaining service life of equipment as stated in Ministerial Regulation No. 32 of 2021, namely Installation and Equipment Safety Inspection in Business Activities. Oil and Gas, for all equipment that has passed the operating design life limit (if known) or is indicated to experience signs of aging that have the potential to disrupt the integrity of the equipment, a Residual Life Assessment (RLA). (23)(24)

Based on the existing problems and following government regulations, a permit for the use of equipment is issued to fulfil the requirements, so it is necessary to perform a Residual Life Assessment (RLA) on the Storage Tank.

2. Corrosion & Remaining Life Assessment

Metal and alloy corrosion is a serious issue that many applications need to address. According to NACE International research from 2016, the global cost of corrosion was 3.4% of the world's GDP, which was around $2.5 trillion at the time (7)

Because of this, corrosion repair and prevention represent one of the single highest economic costs worldwide. Our vehicles, plumbing, structures, bridges, motors, factories, and other items are all damaged or destroyed by corrosion. (1)(8)(9)

Corrosion is particularly pervasive and takes some unique forms in the refining, petrochemical, and chemical industries, in which processing environments involve high temperatures, highly corrosive liquids, and some dry or gaseous environments that facilitate corrosion (10). It takes an interdisciplinary approach from designers, engineers, metallurgists, and chemists to reduce the damaging effects of corrosion. Additionally, engineers and managers who maintain secure, dependable, and economical processing facilities frequently have to analyze corroded equipment to determine its suitability. The American Petroleum Institute (API) 579-1/ASME FFS-1 has been used by the oil and gas industry since 2007 to evaluate the fitness-for-service (FFS) of damaged equipment at their production sites (11).

The code provides detailed guidelines for assessment and acceptance criteria, remaining life assessment, remediation, and in-service monitoring for the continued operation of equipment such as pressurized vessels, piping systems, and storage tanks. Fitness-for-service assessments can be conducted at three levels (1, 2, and 3), with each level requiring increasing amounts of data and inspection of the equipment and level of expertise of the personnel conducting the assessment. API 579-1/ASME FFS-1, Part 4, "Assessment of General Metal Loss;" Part 5, "Assessment of Local Metal Loss;" and Part 6, "Assessment of Pitting Corrosion", provide guidance on how to address the loss of wall thickness due to corrosion.

3. Materials and Procedures

3.1. Materials

The equipment to be studied is the Oil Storage Tank belonging to PT. XYZ with low carbon steel A 36 material. The equipment was chosen because the operation of the storage tank has exceeded 15 – 25 years. (22)

In this study, the method used was a Visual check and UT thickness on the Storage Tank. Thickness data was taken for each plated course and roof on the storage tank.

3.2. Procedures

Visual inspection means the inspection of equipment and structures using a combination of human senses such as sight, hearing, touch and smell. Visual inspections are sometimes carried out in conjunction with devices such as low-power magnifiers, boroscopes, fiber optics, digital video borescopes, camera systems and robotic crawler systems. Visual inspection is the most basic of the various nondestructive test control methods, but it is no less important. (13)

Ultrasonic Testing is an NDT test that utilizes high-frequency sound waves to detect defects or changes in material properties. This test can also be used to measure the thickness of various types of metallic and non-metallic materials where it is enough to check from one side(13). UT Thickness is intended to determine the general corrosion rate at which the tank is operating and can indicate the integrity/worthiness of the tank. Thickness measurements on the tank and nozzle are usually required at every complete inspection of the tank.

The thickness measurement results refer to the thickness report from the results of the inspection carried out.

Residual Life Assessment for Storage Tanks (T-106) evaluates the integrity of the storage tanks and the calculation of the remaining useful life by processing and analyzing construction data and the results of the last inspection in the field. The data obtained are specification data and technical information about equipment, visual observation data and thickness measurement data. The data obtained from the inspection results will be processed into data input in conducting the Residual Life Assessment. The methodology for conducting the assessment is divided into three methods. Evaluation of the strength of the equipment referring to API Std. 650, API Std. 653 & API 579-1/ASME FFS-1.

3.2.1. API 579-1/ASME FFS-1: Fitness-For-Service & API Std. 650 & Std. 653: Standard Design Calculations for Tanks.

The One-foot method calculates the required thickness at the design point 0.3m (1ft) above the bottom of each shell course. The minimum required shell plate thickness must be greater than the value calculated by the following formula:(14)(15)(16)

$$\mathrm{t_d} = \frac{2.6\mathrm{D}(\mathrm{H}-1)\mathrm{G}}{\mathrm{S_d}} + \mathrm{CAt_t} = \frac{2.6\mathrm{D}(\mathrm{H}-1)}{\mathrm{S_t}}$$

$$t_{min} = \frac{2.6\ (\mathrm{H}-1)\mathrm{DG}}{SE}$$

$$t_{min} = \frac{2.6\ \mathrm{HDG}}{SE}$$

- t_{min} The minimum thickness acceptable, in inches, for each course is calculated using the formula above; However, the t_{min} must not be less than 0.1-inch for each tank course.
- D Nominal diameter of the tank, in feet.
- H Height from the bottom of the shell course considering the maximum liquid level when calculating the shell course, in ft; or height of the L base from the lowest point of the L base locally thinned area to the maximum liquid level.
- G Specific gravity of the contents of the stored product.
- S Maximum allowable stress in lbf/in^2, less than 0.80Y or 0.429T for the bottom and second

courses, by using less than 0.88Y or 0.472T for all courses. The allowable stresses in the shell are shown in Table 4-1 API 653.

E Joint efficiency in the tank, using Table 4-2 API653 if E is unknown. E = 1.0 when evaluating the thickness of the corroded plate if it is far from the weld or joint, which is at least 1 or 2 times the thickness of the plate.

Corrosion is defined as damage to the material caused by a chemical reaction with the surrounding environment of material. In the event of corrosion, metal is oxidized, while oxygen (air) is reduced. Metal rust is generally in the form of oxides or carbonates. The chemical formula for iron rust is $Fe_2O_3.nH_2O$, a red-brown solid. Corrosion is an electrochemical process. In iron corrosion, a certain part of the iron acts as the anode, where the iron is oxidized.

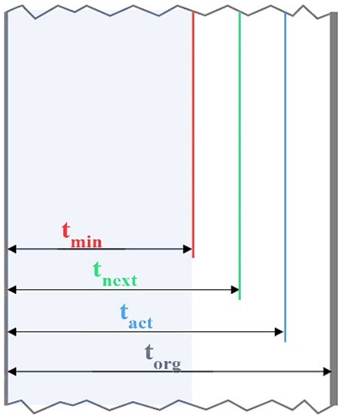
$$Fe(s) \longleftrightarrow Fe^{2+}(aq) + 2e$$

The electrons liberated at the anode flow to another part of the iron which acts as the cathode, where oxygen is reduced.

$$O_2(g) + 4H^+(aq) + 4e \longleftrightarrow 2H_2O(l)$$
$$O_2(g) + 2H_2O(l) + 4e \longleftrightarrow 4OH^-(aq)$$

The corrosion rate is the rate of propagation or deterioration of the material against time. (17)

Statistical analysis can be used to calculate the corrosion rate and the storage tank's remaining service life. This statistical approach can be used to determine inspection intervals. The corrosion rate can be calculated by the following equation. (15)



$$CR = \frac{t_{org} - t_{act}}{\text{Year of Service}}$$

$$CR = \frac{t_{prev} - t_{act}}{\text{Year of Service}}$$

Fig. 1 Various Thickness Level

Long Term

$$\text{Corrosion Rate (LT)} = \frac{t_{initial} - t_{actual}}{\text{time between } t_{initial} \text{ and } t_{actual} \text{ (years)}}$$

Short Term

$$\text{Corrosion Rate (ST)} = \frac{t_{previous} - t_{actual}}{\text{time between } t_{previous} \text{ and } t_{actual} \text{ (years)}}$$

The remaining service life of the tank (in years) is calculated based on the following formula:

$$\text{Remaining Life} = \frac{t_{actual} - t_{required}}{\text{corrosion rate}}$$

Where:

CR	: Corrosion rate(mm/yr)
t. prev	: Previous thickness (mm)
t.act	: Actual thickness (mm)
t.nom	: Nominal thickness (mm)

Acceptance Criteria according to FFS-1 API 579 as follows in table 1. (16)

Table 1. FFS Level 1 Acceptance Criteria

Assessment Parameter	Level 1 Acceptance Criteria
Average Measured Thickness from Point Thickness Readings (PTR)	Determine t_{min} using MFH, S_a $t_{am} - FCA_{ml} \geq t_{min}$
Average Measured Thickness from Critical Thickness Profiles (CTP)	Determine t_{min} using MFH, S_a $t^s_{am} - FCA_{ml} \geq t_{min}$
MFH from Point Thickness Readings (PTR)	Determine MFH_r using $(t_{am} - FCA_{ml})$, S_a $MFH_r \geq MFH$
MFH from Critical Thickness Profiles (CTP)	Determine MFH_t using $(t_{am} - FCA_{ml})$, S_a $MFH_t \geq MFH$
Minimum Measured Thickness	$(t_{mm} - FCA_{ml}) \geq \max [0{,}6\ t_{min}, t_{lim}]$ $T_{lim} = \max [0{,}2\ t_{nom}, 2{,}5 \text{ mm } (0{,}1 \text{ inches})]$
If level 1 FFS is not satisfied, please conduct level 2 FFS	

Where:

FCA_{ml}	Future Corrosion Allowance is applied to the region of metal loss.
MFH	Maximum Fill Height of the undamaged tank.
MFHr	reduced maximum fill the height of the damaged tank.
t_{am}	average measured wall thickness of the component based on the point thickness readings (PTR) measured at the time of the inspection.
t^{s}_{am}	average measured wall thickness of the component based on the longitudinal CTP determined at the time of the inspection.
t_{lim}	limiting thickness.
t_{nom}	The component's nominal or furnished thickness is adjusted for mill under tolerance as applicable.
t_{min}	minimum required wall thickness of the component

3.2.2. ASME PCC-3: Inspection Planning Using Risk-Based Methods

It is used to evaluate damage mechanisms and monitor the inspection of equipment. Damage mechanisms can cause damage/defects, which can later affect the integrity of the equipment, such as corrosion, cracking, erosion, dents and other mechanical impacts. Statistical analysis can be used to calculate the corrosion rate and calculate the storage tank's remaining service life. In aging equipment, it is essential to identify/predict what damage mechanisms have/will occur to the equipment during its operating life. Knowing the type, cause, and morphology of the damage mechanism, it is hoped that the inspection can be carried out in a targeted and efficient manner. In addition, further measures can be developed based on the information obtained to prevent or monitor further aging. (18)

Corrosion occurs on the inside (internal corrosion) and from the outside (external corrosion) on the bottom of the storage tank made of carbon steel. Corrosion of the inner side may cause generalized or localized thinning. The factors that affect corrosion are the characteristics of the corrosivity of the stored product, operating temperature, steam coil practices, and the presence of water in the tank, while corrosion that occurs outside can cause local thinning. Several factors that affect corrosion on the outside are soil type, pad, water draining, cathodic protection, basic tank design and operating temperature for the storage process.

4. Results and Discussion

4.1. Result of the Main Experiment

Based on the research of Enefola S. Ameh, the result showed that No matter how the visual inspection and instrumented nondestructive examination results may appear, the fitness for service evaluation of corrosion-related defects and ageing process equipment in the oil and gas industry is a necessary assessment before making a final decision on rerating, repair, and retirement. (19) The pressure vessel equipment's key fitness for service assessment helped to avoid needless turnaround maintenance and inspections that would have been expensive and disruptive to business. However, despite the fact that the equipment was found safe to continue in use and has 40 years left of its life, it was advised that the localized corrosion be monitored and protected from corrosive environments to stop additional corrosion. (19)

Another Chinese study on tank inspections showed the significance of measuring the thickness at the bottom of the tank to avoid leaks that could result in financial losses. Despite the fact that the bottom of the tank was not examined for this study, it is still crucial to measure the course and roof to assess the tank's integrity in accordance with API 653 about Tank Inspection, Repair, Alteration, and Construction in paragraphs 4.2 – 4.4. (16)(25)

Other studies also focus on the bottom of the tank because even a small leak can cause environmental damage, but the course and roof can also cause damage to the environment and equipment around the tank. (21)

A document review was conducted at the beginning of the study to obtain technical design data and other supporting data. After it has been done, the technical data is obtained, as described in table 2.

Table 2. General Tank Information

General Tank Information	
Tank Name	Storage Tank T-106
Equipment No.	HCT-CTOM-T-106
Construction Code	API Standard 12C
Year Build	1964
Year Previous Inspection	2017
Year Inspection	2021
Nominal Diameter	180. ft
Nominal Height	48 ft
Design Liquid Level	46.83 ft
Nominal Capacity	212.262 Bbl
Geometric Capacity	217.550 Bbl
Content	Oil
Specific Gravity	0.9
Max. Operating Temp.	200 °F
Shell Material	A 36
Roof Material	A 36
Roof type	Cone roof

After obtaining technical data on the equipment, proceed with field inspections to perform visual checks and UT thickness. The actual condition of the oil storage tank can be seen in the following picture.

Fig. 2 Storage Tank T105

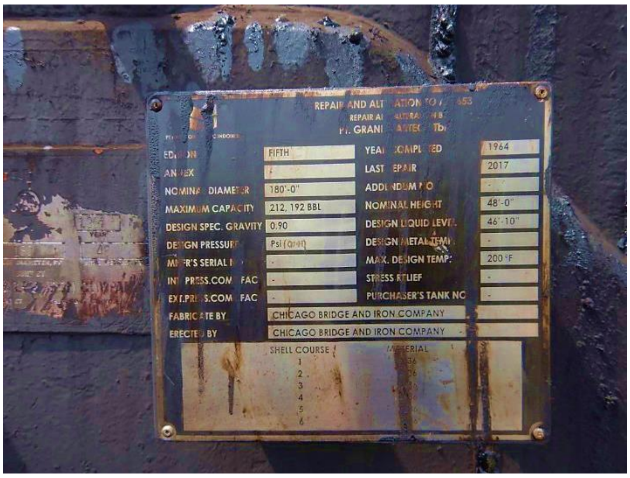


Fig. 3 Name Plate

In general, the storage tank T-105 is in good condition and suitable for operation. The paint coating on the storage tank is still relatively good. Only wild vegetation grows around the storage tank; it is enough to clean it. This visual check process only describes the external condition of the storage tank; internal checks cannot be carried out because the storage tank is in an in-service condition. The inspection rules must carry out internal checks in API 653.

After measuring the UT thickness on the storage tank, the results of the UT thickness can be seen in table 5.

Table 5. Thickness Measurement

UT Thickness	Nom.Thk (mm)	Act. Thk (mm)
Roof Plate	6.35	5.76
Bottom Plate	N/A	N/A
Course 1	33.64	31.69
Course 2	26.94	26.30
Course 3	20.68	20.72
Course 4	15.87	15.40
Course 5	10.54	10.15
Course 6	8.24	6.50

Based on the UT thickness measurement table, the most negligible thickness is the roof, with a thickness of 5.76 mm, and the most insignificant course thickness on course 6, with a thickness of 6.50 mm. with the thickness data obtained. The feasibility calculation is carried out according to the API 579 standard. The first stage is to Calculate the Minimum Required Thickness (tmin).

$$t_{min} = \frac{2.6 \text{ HDG}}{SE}$$

Table 6. Calculate the Minimum Required Thickness

Calculation	Tmin (mm)
Roof Plate	2.29
Course 1	22.19
Course 2	18.46
Course 3	14.74
Course 4	11.01
Course 5	7.29
Course 6	3.56

The next step is to calculate the corrosion rate of the storage tank. In calculating the corrosion rate this time, the long-term is used due to the absence of previous thickness data.

$$\text{Corrosion Rate (LT)} = \frac{t_{initial} - t_{actual}}{\text{time between } t_{initial} \text{ and } t_{actual} \text{ (years)}}$$

The following table shows the corrosion rate results for each course and roof.

Table 7. Corrosion Rate

Item	CR (mm/year)
Roof Plate	0.010
Course 1	0.034
Course 2	0.011
Course 3	-0.001
Course 4	0.008
Course 5	0.007
Course 6	0.031

The highest corrosion rate value is 0.034 mm/year, which will be used to determine FCA.

The next step is to calculate the component height assuming the course height is 2,379 m and the number of courses is 6. The fill height for each course is obtained as follows.

$$MFH = \frac{\text{t S}}{2.6\ DG}$$

Table 8. Fill Height of each Course

Item	H (m)
Course 1	20.98
Course 2	17.08
Course 3	13.41
Course 4	10.06
Course 5	6.73
Course 6	4.57

The next step is calculating Tmin according to the acceptance criteria per table 4.6 API 759.

Table 9. Tmin, according to API 579

Item	T_{am}- FCA	≥	T_{min}	Results
Course 1	32.38 mm	≥	22.19 mm	OK
Course 2	26.28 mm	≥	18.46mm	OK
Course 3	20.53 mm	≥	14.74 mm	OK
Course 4	15.29 mm	≥	11.01 mm	OK
Course 5	10.07 mm	≥	7.29mm	OK
Course 6	6.69 mm	≥	3.56 mm	OK

The next step is calculating the MFH acceptance criteria in Table 4.6 API 759.

Determine MHF, using (T_{am} – FCA), S_a, H_f

Table 10. Acceptance Criteria Maximum Fill High According to API 579

MFH≥MFHItem	MFH_r (m)	≥	MFH (m)	Result
Course 1	20.98	≥	14.27	OK
Course 2	17.08	≥	11.89	OK
Course 3	13.41	≥	9.52	OK
Course 4	10.06	≥	7.14	OK
Course 5	6.73	≥	4.76	OK
Course 6	4.57	≥	2.38	OK

From the calculation results in the table, The calculated MFHr value is still above the MFH fill height value. In other words, the actual MFH value is still within the tolerance limit.

The next step is calculating Tlim from the course by the acceptance criteria as per table 4.6 API 579.

$(t_{mm} – FCA_{ml}) \geq \max [0,6\ t_{min}, t_{lim}]$
$T_{lim} = \max [0,2\ t_{nom}, 2,5 \text{ mm } (0,1 \text{ inches})]$

The following table shows the calculation result of the minimum measured thickness for each course in the storage tank.

Table 11. Minimum measured thickness

Item	T_{limts} (mm)
Course 1	6.73
Course 2	5.39
Course 3	4.14
Course 4	3.17
Course 5	2.50
Course 6	2.50

Table 12. Acceptance Criteria Minimum measured thickness According to API 579

Item	T_{mm}- FCA	≥	0.6 T_{min}	Result
Course 1	31.39 mm	≥	13.31 mm	OK
Course 2	26.00 mm	≥	11.08 mm	OK
Course 3	20.42 mm	≥	8.84 mm	OK
Course 4	15.10 mm	≥	6.61 mm	OK
Course 5	9.85 mm	≥	4.37 mm	OK
Course 6	6.20 mm	≥	2.50 mm	OK

From the calculation results, the minimum measured thickness value is still within the minimum limit according to the acceptance criteria from API 579. Furthermore, the remaining life calculation is by the standard code API 579 paragraph 4.51.

$$\text{Remaining Life} = \frac{t_{actual} - t_{required}}{\text{corrosion rate}}$$

Table 13. Remaining life

Item	R_{life} (year)
Course 1	20
Course 2	20
Course 3	20
Course 4	20
Course 5	20
Course 6	20
Roof	20

Based on the remaining life calculation, the remaining service life of the storage tank is 20 years.

5. Conclusion

From the results of the thickness test, the storage tank was experiencing general corrosion, the lowest thickness value of the storage tank is on the roof, with a value of 5.76 mm, while the highest thickness value is on course 1, which is 31.69 mm, while the highest corrosion rate value is on course 1 with a value of 0.034 mm/year from the corrosion value. The remaining life rate obtained from the T-106 storage tank is 20 years.

In PT XYZ's T-106 Storage Tank, no significant anomalies were found during the inspection that might affect the storage tank's ability to continue operations safely. However, it is recommended to maintain the condition of the storage tank so that it remains in its service function.

From the screening table above, the damage mechanisms that may occur in the storage tank include the following:

Table 3. Damage Mechanism

No.	Damage Mechanism	Mode	Possibility	Definition	Position	Description
1	Uniform Corrosion	Metal Loss	High (Refer to API RP 581 Section 2.B.11.3.3)	It is a form of corrosion damage where there is a uniform thickness reduction on the surface, mostly due to the atmosphere of the condition.	Course 1 Shell, Course 2 Shell, Course 3 Shell, Course 4 Shell, Course 5 Shell, Course 6 Shell Roof, Bottom	- Equipment exposed to the atmosphere - Corrosion rate (CR) = 0.034 mm / year
2	Under Deposit Corrosion	Metal Loss	None	A special version of crevice corrosion	Bottom	- Material Carbon Steel
3	Erosion / Erosion – Corrosion	Metal loss	None	The accelerated mechanical transfer of metal due to relative movement between the corrosive fluid and the metal surface. As well as damage that occurs due to the corrosive environment and the relative motion between the environment and the material, which mostly occurs in the fluid transfer system (pipeline)	Course 1 Shell, Course 2 Shell, Course 3 Shell, Course 4 Shell, Course 5 Shell, Course 6 Shell Roof, Bottom	- Equipment = Storage Tank
4	Naphthenic Acid Corrosion	Metal loss	None	It is a non-aqueous corrosion process caused by naphthenic acid. Naphthenic acid corrosion is a problem for refineries that contain high levels of naphthenic acid at high temperatures. This usually affects crude oil units, vacuum units, and downstream units. The corrosion behaviour of naphthenic acids can be time-variant, localized, and difficult to predict.	Course 1 Shell, Course 2 Shell, Course 3 Shell, Course 4 Shell, Course 5 Shell, Course 6 Shell Roof, Bottom	- The fluid does not contain Naphthenic Acid - Corrosion rate (CR) = 0.034 mm / year

Based on the inspection and monitoring method that has been carried out, the recommended inspection plan for this storage tank is as follows :

Table 4. Inspection Plan

No.	Damage Mechanism	Method		Inspection Plan (*)	Area
1	Uniform Corrosion	Surface	Visual Inspection (Including Borescope)	Visual inspection >90% of exposed surface area by following up UT, RT, or pit gauge as needed.	Roof, Bottom & Shell
		Subsurface	Ultrasonics for Thickness		
			Ultrasonics—Straight Beam		
			Ultrasonics—Shear Wave		
			Ultrasonics—Shear Wave Adv. Techniques		
		Other Methods	Dimensional Measurements		
2	Under Deposit Corrosion	Subsurface	Ultrasonics for Thickness	Visual inspection of <5% of exposed surface area by following up UT, RT, or pit gauge as required.	Bottom of Shell
			Ultrasonics—Straight Beam		
		Other Methods	Boat/Plug Sample		
3	Erosion / Erosion – Corrosion	Surface	Visual Inspection (Including Borescope)	Visual inspection of <5% of exposed surface area with follow-up UT, RT, or pit gauge as needed.	Roof, Bottom & Shell
		Subsurface	Ultrasonics for Thickness		
			Ultrasonics—Straight Beam		
3	Erosion / Erosion – Corrosion	Subsurface	Ultrasonics—Shear Wave	Visual inspection of <5% of exposed surface area by UT, RT, or pit gauge follow-up as required.	Roof, Bottom & Shell
			Ultrasonics—Shear Wave Adv. Techniques		
		Other Methods	Dimensional Measurements		
4	Naphthenic Acid Corrosion	Surface	Visual Inspection (Including Borescope)	Visual inspection of <5% of exposed surface area by following up UT, RT, or pit gauge as needed.	Roof, Bottom & Shell
		Subsurface	Ultrasonics for Thickness		
			Radiography		

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