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Development Fitness-for-Service Application Program with Case Study on Equipment Used in Oil and Gas Sector

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Abstract

Fitness For Service (FFS) analysis is very usefull for maintenance and inspection in order to make post inspection analysis, especially to take decision about run, repair or re-rate. As time went on and interaction with the environment, those equipments will be degraded thus it will affect the reliability of equipments, and company needs to analyze the effect of degradation for equipments lifetime by using FFS methods. In order to reactivate or increase component lifetime in oil and gas facility, many parameters and quantification method is needed because of the high risk of oil and gas operating condition. In this final task, the equipment has been analyzed using standard API 579 section 4, 5, 9 and 14 for levels 1 and 2. The method consists of several steps complex mathematical calculations, so to make it easier to do analysis writer has developed software for the calculation of each of these levels using Visual Basic 2012. Many case studies also carried out in static mechanical equipment, which include vertical storage tank (DSTs and ST), cone mixer and KO Drum. The case study is taken from oil and gas storage facility which has been used for more than 10 years. From the results of the inspection can be concluded that mostly in storage tanks will occurs general corrosion (thickness covarians < 10%), but there are many possibilities that localize thin area (LTA) also happen. For equipments that damaged by LTA, root cause analysis should be done in order to stop the LTA and solve the corrosion problem. Equipments that has crack like flaw (CLF) and fatigue, FFS analysis should be done and if those equipments pass the FFS assessment then normal operation still can continue without any major repair. In the last research writer has analyze parameters that can affect the integrity of the components that has general corrosion, LTA and CLF. Where with the increasing values of the parameters then the integrity of the components will be decreased so that it becomes unsafe to operate.

Keywords: Fitness For Service, Corrosion in Storage Tanks, Corrosion and Cracks in Pressure Vessels, and Fatigue in Mixers.

Introduction

Over time and equipment that has been operating for a long time, production equipment will experience reduced reliability and malfunctions due to degradation such as corrosion, geometric defects, or cracks. Therefore, to see the effects of degradation on the reliability and service life of the equipment, it is necessary to analyze it using certain methods, one of which is fitness for service (FFS) with reference to the API 579 standard. FFS analysis uses 3 stages, namely level 1, level 2 and level 3, this describes the actual condition of the equipment indicated by the remaining strength factor (RSFa). Level 1 analysis (RSFa = 0.9) means that the equipment is still suitable for normal operation, but if it does not pass level 1 then level 2 analysis (RSFa = 0.8-0.9) and level 3 analysis (RSFa = 0.7) can also be used, but of course there are consequences that must be done by the owner such as the application of RBI (risk based inspection) and / or the addition of safeguards to improve safety integrity level. At level 3 analysis, finite element method (FEM) analysis and microstructure analysis must also be carried out to calculate the remaining life of the equipment. In this study, the analysis was only carried out for levels 1 and 2, because there was no destructive test for existing sarfas and there was no additional safety. Not all equipment can also be applied level 1 analysis, if there are external forces that affect the strength of components significantly then level 2 analysis must be done.

Fitness For Service (FFS) Assesment

FFS is a quantitative analysis used to determine the integrity and residual life of a component, as well as to make decisions to run, repair, or replace a degraded component. FFS analysis based on API 579 is specifically prepared to analyze pressurized static components such as tanks, pressure vessels, piping and pipelines. FFS cannot be applied in active components (rotating/dynamic) such as pumps, compressors, or blowers. In FFS, the assessment of the residual life of a component must be applied by a group of people, or by a person (if only has an expert) who has expertise in 5 (five) disciplines, namely materials and corrosion, code and standard stress analysis, fabrication and welding, inspection and operation of a system to be evaluated.

Method

Equipment used

The main equipment used for inspection are: Ultrasonic thickness meter, crawler, vacuum box, magnetic particle leakage and yoke. All of these tools must be certified by the Director General of Meteorology and are still in suitable condition.

Ultrasonic Thickness Meter

This tool serves to measure the actual thickness of the plate on the tank wall by utilizing ultrasonic waves, but this tool can only be used when the tank condition is not operating (offstream). To take measurements used sensors. This equipment was developed for permanent installations such as pipes and vessels. This equipment can work at temperatures up to 120 ^{0C} and has 1 (one) sensor attached directly to the plate. To reach the top tank wall, of course, tools such as ladders, stagers and rafling equipment are needed.

Figure 1. Ultrasonic Thickness Meter

Magnetic Flux Leakage Floor Scanner and Magnetic Flux Yoke

MFL floor scanner serves to measure the thickness of the plate on the tank floor by utilizing a strong magnetic field while the magnetic yoke is usually to see if there is a defect in the tank wall weld. MFL floor scaner is very suitable for measuring the thickness of the bottom plate because several plates on the tank floor are overlapped. This tool is also used when the condition of the tank is offstream.

Figure 2. Magnetic flux leakage and yoke

Crawler

Crawler is a robot equipped with ultrasonic sensors so that it can be used to measure the plate thickness of all parts of the tank, including the bottom plate, shell and roof of the tank. The advantage of this tool can be used in operating conditions / onstream.

Figure 3. Crawler for thick drubbing of plates on the walls of the tank.

Vacuum Box Testing

Vacuum Box Testing is used if there is an area on the tank floor that is indicated to have a leak. This tool works by applying suction pressure (0-15 psi) on the tank floor and on the other hand given fluid / foam and then held at a certain grace period (10-30 seconds) to ensure foam does not propagate to other surfaces. To detect fine leaks, you can also use a vacuum box with a larger pressure, which is 21 – 35 KPa.

Figure 4. Vacuum Box Testing

Theodolit

This tool is used to measure the slope and roundness of the tank roof. To measure slope, a benchmark point is needed as a reference. The maximum allowable slope of the tank is 1/200.H.

Figure 5. Theodolit

Result And Discussion

Inspection data from an oil and gas company is classified as confidential data. Therefore PT. XYZ cannot provide all the results of the inspection that has been carried out. PT. XYZ only provides detection data on 5 (five) equipment that has been inspected, namely: 2 units of double wall storage tanks / DSTs (T-6402/6403), 1 unit of storage tank (T-007), 1 unit of drum (D-6406) and 1 unit of mixing vessels. Because PT. XYZ provides limited data, so it cannot be given a comprehensive conclusion on the remaining life of a plant. In this chapter the author also does not provide inspection result data and detailed calculation process to make it easier to understand, while the inspection result data and detailed calculation process are in the appendix.

FFS for tanks D-6402

The general description of this tank is as follows:

- Material = ASTM A 537 Grade 2
- Diameter = 71,2 meter or 233,6 feet
- Tank height = 24,03 meter or 78,84 feet
- Maximum height of fill fluid = 23,04 meter or 75,59 feet
- Specific gravity of the fill fluid = 0,58 gr/cm^3 or 0,036 lbs/ft^3.
- Specific gravity of carbon steel = 7858 kg/m^3
- Theoretical volume of accommodated fluid = 95.676 m^3 atau 3.378.771 ft^3
- Actual volume of the contained fluid = 525.000 barrel atau 84.000 m^3
- Design force voltage / yield = 50.000 psi
- Maximum pressure strength = 54.000 psi or 165,47 MPa
- Number of courses = 9, then the width of the plate used in each course is 2.8 meters or 9.2 ft.

- The tank was built in 1988 or is already 28 years old.

Based on the results of reverse engineering using equations (2.1) to (2.10), the thickness of the plate on each course, floor and roof are as follows:

Table 1. Reverse engineering results on the propane tank shell plate.

unit = mm	C1	C2	C3	C4	C5	C6	C7	C8	C9
$t_1 = t_{min}^C$	23,87	20,29	17,56	14,87	12,18	9,49	6,81	4,13	1,47
$t_{H1} = t_{min}^L$	21,36	18,70	15,97	13,27	10,57	7,87	5,17	2,47	2,47
CA	1,50	1,50	1,50	1,50	1,50	1,50	1,50	1,50	1,50
T_{Needed}	25,37	21,79	19,06	16,37	13,68	10,99	8,31	5,63	3,97
$t_{nominal}$	28	24	22	18	16	12	10	10	10

Table 2. Reverse engineered results on the floor and roof of the propane tank.

Unit = mm	Annular	Floor	Roof
$t_1 = t_{min}^C$	19,05	4,47	3,55
$t_{H1} = t_{min}^L$	12,19	4,32	0
CA	1,5	1,5	1,5
T_{Needed}	19,05	5,97	5,05
$t_{nominal}$	20	8	6

After doing reverse engineering and supporting data obtained, FFS analysis can be carried out as follows:

Table 3. FFS results on propane tank walls.

Unit = mm	C1	C2	C3	C4	C5	C6	C7	C8	C9
Component Type	B1	A	A	A	A	A	A	A	A
t_{mm}	23,00	23,00	20,06	17,39	14,01	9,55	9,55	9,55	9,58
t_{am}	26,49	23,12	20,39	17,58	14,07	10,59	9,71	9,70	9,67
COV (%)	0,13	0,3	2,6	0,53	0,44	0,9	0,9	0,2	0,2
$t_{corrosion}$	1,51	0,88	1,61	0,42	1,93	1,41	0,29	0,33	0,33
FCA_{ml}	0	0,62	0	1,08	0	0,09	1,21	1,17	1,17
t_{sisa}	1,5	-	2,51	-	1,81	-	-	-	-
Amount of Data, i	136	18	15	15	15	15	15	15	15
Level requirements. 1	$\mathbf{t_{am} - FCA_{ml} \geq t_{min}^C}$								
Level 1 Assessment	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed

Level requirements. 2	**t_{am}-$FCA_{ml} \geq RSFa.t_{min}$**								
Level 2 Assessment	Passed	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CR (mm/thn)	0,05	0,035	0,057	0,057	0,07	0,05	0,01	0,01	0,01
Umur (thn)	30	19	44	19	25	2	121	121	121

Table 4. FFS results on propane tank floor and roof.

Unit = mm	Annular	Floor	Roof
Component Type	B1	A	A
t_{mm}	18,85	5,9	4,51
t_{am}	19,06	6	4,61
COV (%)	0,4	0,6	3
$t_{corrosion}$	0,94	2	1,39
FCA_{ml}	0,56	0	0,11
t_{sisa}	-	1,43	-
Amount of Data, i	240	630	147
Level 1 requirements	**$t_{am} - FCA_{ml} \geq t_{min}^{C}$**		
Level 1 Assessment	Passed	Passed	Passed
Level 2 requirements	**$t_{am} - FCA_{ml} \geq RSFa.t_{min}$**		
Level 2 Assessment	Passed	N/A	N/A
CR (mm/thn)	0,03	0,07	0,05
Residual Age (thn)	18,6	20,4	3

In addition to analyzing the plate wall, we also need to check the slope and roundness of the tank roof. The tank slope limit is 1/200.H = 356 mm while the maximum allowable roundabout is 13 mm. Based on the inspection results, elevation measurement data around the roof of the tank is obtained as shown in the table below.

Based on the calculations above, it can be concluded that the tank is still suitable for use with an estimated remaining life of 2 years. The average corrosion rate in all components is 0.04 mm / year so the corrosion rate is still considered reasonable. A reasonable corrosion rate in storage tanks [13] is 2 mpy or 0.05 mm/year.

FFS for tank D-6403.

The general description of this tank is as follows:

- Material = ASTM A 516 Grade 70
- Diameter = 70,1 meters or 229,99 feet

- Tank height = 24.5 meters or 80,38 feet
- Maximum height of fill fluid = 23.04 meters or 75,59 feet
- Specific gravity of the fill fluid (butane) = 0,597 gr/cm^3 or 0,037 lbs/ft^3.
- Specific gravity of carbon steel = 7858 kg/m^3
- Theoretical volume of accommodated fluid = 94.556 m^3 or 3.339.236 ft^3
- Actual volume of fluid accommodated = 525.000 barrel or 84.000 m^3
- Design force voltage / yield = 38.000 psi
- Maximum pressure strength = 21.000 psi or 144,79 MPa
- Number of courses = 9, then the width of the plate used in each course is 2.8 meters or 9.2 ft.
- The tank was built in 1988 so it was concluded that the tank was 28 years old.

Based on the results of reverse engineering using equations (2.1) to (2.10), the thickness of the plate in each course is as follows:

Table 5. Reverse engineering results on butane tank shell plate.

unit = mm	C1	C2	C3	C4	C5	C6	C7	C8	C9
$t_1=t_{min}^C$	25,56	21,00	18,92	16,09	13,26	10,44	7,62	4,81	2,01
$t_{H1} = t_{min}^L$	12,48	10,96	9,00	7,92	6,40	4,76	4,76	4,76	4,76
CA	1,50	1,50	1,50	1,50	1,50	1,50	1,50	1,50	1,50
$t_{dibutuhkan}$	27,06	22,50	20,42	17,59	14,76	11,94	9,12	6,31	6,26
$t_{nominal}$	28	24	22	18	16	12	10	10	10

Table 6. Reverse engineering results on the floor and roof of the butane tank.

unit = mm	Annular	Floor	Roof
$t_1=t_{min}^C$	19,05	4,47	3,55
$t_{H1} = t_{min}^L$	12,19	4,32	0
CA	1,5	1,5	1,5
T_{Needed}	19,05	5,97	5,05
$t_{nominal}$	20	8	6

After doing reverse engineering and supporting data obtained, FFS analysis can be carried out as follows:

Table 7. FFS analysis on butane tank wall.

Unit =mm	C1	C2	C3	C4	C5	C6	C7	C8	C9
Component Type	B1	A	A	A	A	A	A	A	A
t_{mm}	27,42	24,29	20,39	17,39	13,99	10,29	9,55	9,67	9,58

t_{am}	27,79	24,37	20,39	17,58	14,07	10,59	9,71	9,70	9,67
COV (%)	0,5	0,2	2,6	0,53	0,44	0,9	0,6	0,2	0,2
$t_{corrosion}$	0,21	0,37	1,61	0,42	1,93	1,41	0,29	0,3	0,33
FCA_{ml}	1,29	1,13	0	1,08	0	0,09	1,21	1,20	1,17
t_{sisa}	-	-	1,14	-	0,73	-	-	-	-
Amount of Data, i	135	15	15	15	15	15	15	15	15
Terms lev 1	$\mathbf{t_{am} - FCA_{ml} \geq t_{min}^C}$								
Level 1 Assessment	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed	Passed
Terms lev 2	$\mathbf{t_{am} - FCA_{ml} \geq RSFa.t_{min}}$								
Level 2 Assessment	Passed	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CR (mm/thn)	0,007	0,023	0,057	0,015	0,07	0,05	0,01	0,01	0,01
age (thn)	172	60	20	19	10	2	121	120	121

Table 8. FFS analysis on butane tank floor and roof.

unit = mm	**Annular**	**Floor**	**Roof**
Component Type	B1	A	A
t_{mm}	18,85	5,9	4,51
t_{am}	19,86	6,12	4,61
COV (%)	2	2,5	3
$t_{corrosion}$	0,14	1,88	1,39
FCA_{ml}	1,36	0	0,11
t_{sisa}	-	1,5	-
Amount of Data, i	180	125	147
Level 1 requirements	$\mathbf{t_{am} - FCA_{ml} \geq t_{min}^C}$		
Level 1 Assessment	Passed	Passed	Passed
Level 2 requirements	$\mathbf{t_{am} - FCA_{ml} \geq RSFa.t_{min}}$		
Level 2 Assessment	Passed	N/A	N/A
CR (mm/thn)	0,005	0,067	0,05
Residual Age (thn)	172	22	3

Based on the calculations above, it can be concluded that the tank is still suitable for use with an estimated remaining life of 2 years. The average corrosion rate in all components is 0.03 mm / year so the corrosion rate is still considered reasonable. A reasonable corrosion rate in storage tanks [13] is 2 mpy or 0.05 mm/year.

FFS for T-007 tanks

The general description of this tank is as follows:

- Material = ASTM A 283 Grade C
- Diameter = 29.27 meters or 96 feet
- Tank height = 24.5 meters or 80,38 feet
- Maximum height of fill fluid = 11.1 meters or 36,42 feet
- Specific gravity from Solar = 0,86 gr/cm^3 atau 13,85 lbs/ft^3.
- Specific gravity of carbon steel = 7858 kg/m^3
- Theoretical volume of accommodated fluid = 7.459 m^3 or 263.412 ft^3
- Actual volume of fluid accommodated = 43.750 barrel or 7.000 m^3
- Design force voltage / yield = 19.870 psi or 137 MPa
- Maximum pressure strength = 22.335 psi or 154 MPa
- Number of courses = 6, then the width of the plate used in each course is 2.1 meters or 6.9 ft.
- The tank was built in 1988 so it was concluded that the tank was 28 years old.

Based on the results of reverse engineering using equations [2.12] to [2.13], the thickness of the plate in each course is as follows:

Table 9. Reverse engineering results on the shell plate of the solar tank.

unit = mm	C1	C2	C3	C4	C5	C6
$t_1 = t_{min}^C$	13,36	11,14	8,94	6,69	4,47	3,20
$t_{H1} = t_{min}^L$	13,82	10,84	9,22	6,92	4,62	3,31
CA	2	2	2	2	2	2
t_{Needed}	15,82	13,14	11,22	8,92	6,62	5,31
$t_{nominal}$	18	14	12	10	10	10

Table 10. Reverse engineered results on the floor and roof of the solar tank.

unit = mm	Annular	Floor	Roof
$t_1 = t_{min}^C$	4,57	6,00	4,57
$t_{H1} = t_{min}^L$	4,32	4,32	4,32
CA	3	3	1,5
t_{Needed}	7,57	9	6,07
$t_{nominal}$	8	10	8

After doing reverse engineering, it is also necessary to find the need for plate thickness due to circumferential and longitudinal stresses for used tanks using the equations [2.14] and [2.15], then FFS analysis can be carried out as follows:

Table 11. FFS analysis on the wall of the solar tank.

unit = mm	C1	C2	C3	C4	C5	C6
Component Type	B1	A	A	A	A	A
t_{mm}	12,45	9,36	9,09	7,22	7,17	8,34
t_{am}	13,16	11,42	10,07	8,45	8,36	8,34
COV (%)	2,70	8,5	4,8	8,1	7,7	7,7
$t_{corrosion}$	4,84	2,58	1,93	1,55	1,64	1,66
t'^{C}_{min}	8,02	7,58	7,32	5,45	3,58	1,7
t'_{Hi}	11,86	9,7	7,48	5,76	3,78	1,8
FCA_{ml}	0	0	0,07	0,45	0,36	0,34
t_{sisa}	0,59	-0,34	-	-	-	-
Amount of Data	80	40	40	40	40	40
Terms Lev 1	$t_{am}-FCA_{ml} \geq t^{C}_{min}$					
Level 1 Assessment	Passed	Not Passed	Passed	Passed	Passed	Passed
Terms Lev 2	$t_{am}-FCA_{ml} \geq RSFa.t_{min}$					
Level 2 Assessment	Passed	N/A	N/A	N/A	N/A	N/A
CR (mm/thn)	0,17	0,09	0,07	0,05	0,06	0,06
age (thn)	3,47	-	1	9	6	5,6

Table 12. FFS analysis on the floor and roof of the solar tank.

unit = mm	Annular	Floor	Roof
Component Type	B1	A	A
t_{mm}	7,98	7,26	3,7
t_{am}	8,91	8,34	4,8
COV (%)	7,7	5,92	34,8
$t_{corrosion}$	1,09	1,66	1,2
t'^{C}_{min}	6	6	2,3
t'_{Hi}	2,44	2,44	0
FCA_{ml}	1,91	1,34	0,3
t_{sisa}	-	-	-
Amount of Data, i	18	36	98
Level 1 requirements	$t_{am} - FCA_{ml} \geq t^{C}_{min}$		

Level 1 Assessment	**Passed**	**Passed**	**Passed**
Level 2 requirements	$t_{am} - FCA_{ml} \geq RSFa.t_{min}$		
Level 2 Assessment	**Passed**	**N/A**	**N/A**
CR (mm/thn)	**0,04**	**0,06**	**0,04**
Residual Age (thn)	**47**	**22**	**7,5**

Based on the table above, there can be indications of local thinning areas, it is necessary to further analyze the causes of local thinning areas so that the corrosion process can be stopped. Here is a fishbone diagram to analyze the causes of local depletion areas.

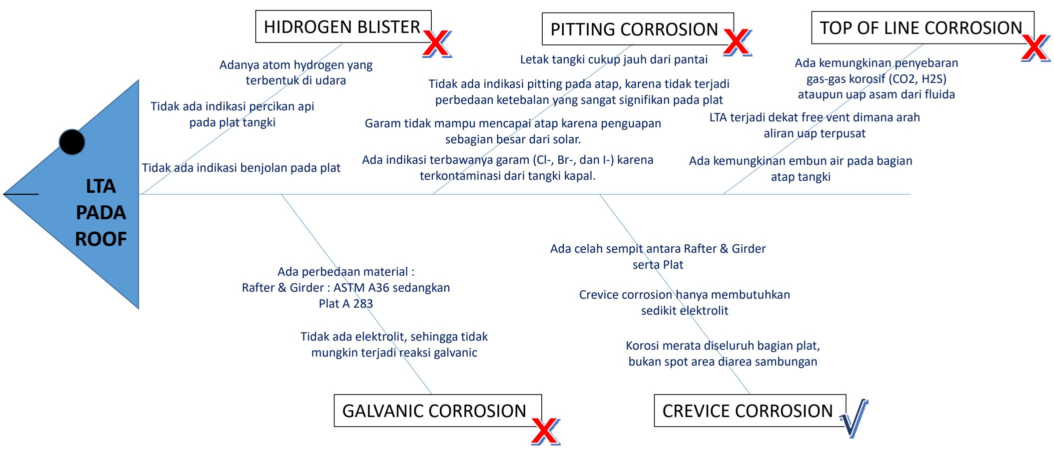

Figure 6. Diagram of fish bones on the roof of the tank

Based on the fish bone diagram above, it can be concluded that on the roof of the tank there is narrow gap corrosion / crevice corrosion and to overcome this, you can use a coating on the roof plate of the tank or use Teflon paper between the roof plate and the reinforcing structure. In addition, based on the above calculations, it can be concluded that the tank is not suitable for reuse, therefore it must be repaired. The average corrosion rate in all components is 0.07 mm / year so the corrosion rate is considered unnatural. A reasonable corrosion rate in storage tanks [13] is 2 mpy or 0.05 mm/year. Then it is recommended that the tank be provided with cathodic protection.

FFS for LPG drum (D-6408)

The general description of this tank is as follows:

- Material = ASTM SA 516 Grade 60
- Yield strength / yield = 17100 psi
- Diameter = 2.79 meters or 110 inch
- Thick nominal plate on wall and head = 18 mm = 0,644 inch
- Tank length = 10 meters or 393.7 inch
- Maximum height of fill fluid = 11.1 meters or 36,42 feet
- Design Pressure / MAWP = 64 psi
- Operating Temperature -50 ^{o}F

- Crack occurs in the nozzle area (N3 #300-3/4 inch) for the instrument. Crack length = 87.98 mm and depth 2.5 mm.
- The tank was built in 1988 so it was concluded that the tank was 28 years old.

The following is a reverse engineering analysis to determine the thickness of the plate thickness requirement, namely by finding the plate thickness needed to overcome circumferential and longitudinal stresses based on the equations [2.11] and [2.12], namely:

Table 13. Reverse Engineering Results on LPG Drums.

Thick Plate : inch	Tank Wall	Head
t_{min}^{C}	0,207	0,1
t_{min}^{L}	0,103	0,103
CA	0,125	0,125
t_{min}	0,332	0,228
$t_{nominal}$	0,708 / 18 mm	0,708 / 18 mm

Based on the data above, FFS level 1 analysis was carried out, namely:

1. Determine the maximum depth and maximum length of crack that can be analyzed with level 1 and level 2. Based on the calculations in annex L.4.2 it can be seen that the maximum depth is 4.5 mm and the maximum length is 4.2 inches. Then the crack that occurs can still be analyzed with level 1 and level 2.
2. Create a failure analysis diagram:

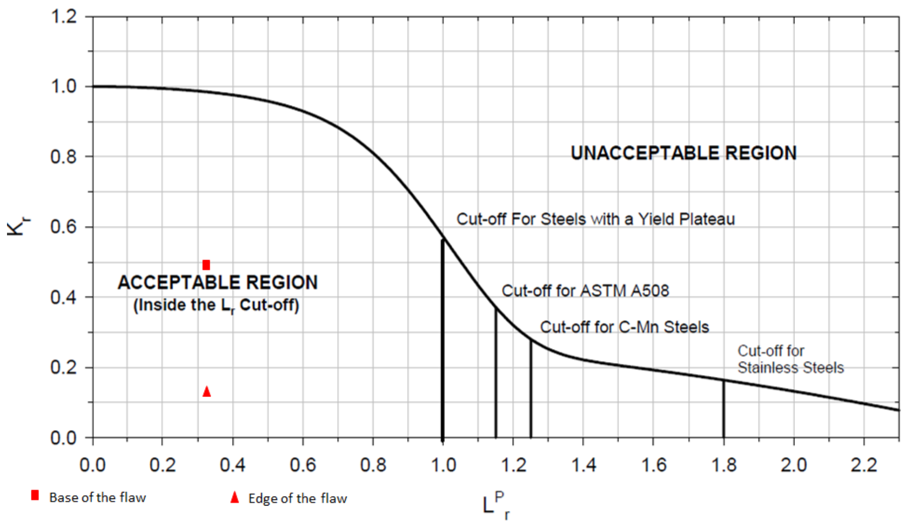

Figure 7. FAD results for LPG drums (D-6408)

After mapping the plastic interaction factors, L_r^P and the power ratio, Kr turns out CLF is still in the safe zone so that the tank can be reused. In addition to conducting CLF analysis, it is also necessary to analyze the corrosion evenly and the residual age based on corrosion rate. Because the diameter of the tank is smaller than the length of the tank, corrosion analysis must use a critical thickness profile. Here is the FFS process performed:

Table 14. FFS Analysis Results on LPG drums.

Thick in : inch	Circumferential	Longitudinal
t_{am}	0,565	0,570
$t_{corrosion}$	0,079	0,074
FCA	0,046	0,051
Level 1 Requirements	t_{am}^{C} - FCA > t_{min}^{C}	t_{am}^{L} - FCA > t_{min}^{L}
Level 1 Assessment	Passed	Passed
Level 2 Requirements	t_{am}^{C} - FCA > RSFa.t_{min}	t_{am}^{L} - FCA > RSFa.t_{min}
Level 2 Assessment	Passed	Passed
CR	0,07 mm/year	0,07 mm/year
Residual Age	16 Years	18 Years

Based on the calculations above, it can be concluded that the tank is still suitable for use with an estimated remaining life of 16 years. The average corrosion rate in all components is 0.07 mm / year so the corrosion rate is still considered unnatural. A reasonable corrosion rate in storage tanks [13] is 2 mpy or 0.05 mm/year. It is recommended to use internal coating. In this tank it is not recommended to use cathodic protection because the corrosion rate is more caused by oxygen from free air because the tank has not been used for a long time, if the tank will be reactivated the corrosion rate will decrease.

FFS for mixing vessels

The general description of this tank is as follows:

- Material = ASTM SA 516 Grade 485
- Yield strength / yield = 38000 psi
- Tensile stress strength of the material / UTS = 70.000 psi
- Head and shell diameter = 1.84 meters or 72,24 inch
- The diameter of the bottom is tapered at an angle of 40 degrees.
- Specific gravity of asphalt fluid = 1040 kg/m3.
- Asphalt fluid capacity = 2,5 m3
- Motor rotation speed = 1470 rpm = 154 rad/detik
- Centripetal force = 217 psi
- Design Pressure / MAWP = 136 psi
- Operating Temperature 165 ºC.
- The tank was built in 2002 or the tank is 10 years old.

In addition to corrosion, this tank also occurs phatic voltage, which is voltage caused by pressure and temperature fluctuations. Here is the FFS process for fatigue loads:

1. Conducting Level 1 Analysis.

- Identify the number of times equipment shutdown: 5 times / per year. Then in 1 year there is a possibility of 73 days the tank stops working. In these 73 days the pressure change range is only 0 to 136 psi.

- Identify the range of pressure changes during operation, which is 136 – 531 psi. In the plant there are 4 stockpile tanks and 4 mixing vessels, so there is a possibility that 1/4 of the time of operation of the tank is not supplied with fluid because the tank is empty.
- The material used is ASTM SA 516 Gr. 485 or still classified as carbon steel so that the material coefficient due to temperature fluctuations is obtained (m,n) = (3x0,2) = 0,6.
- Temperature changes occur in the range of 0-165 ^{oC} so that referring to table 14.1 API 579 temperature factor obtained 8.
- Based on this, a table of possible fluctuations in operations is created.

Table 15. Calculation of operating fluctuations in mixing vessels.

Changes in Conditions	Pressure Changes	Temperature Factor	Material Fakor due to ΔT	Operation Fluctuations
5 (ON/OFF)	=24x365/5x136 = 238,272	=8x5 = 40	0,6	238,318
4 (Operasi)	=24x292x(351-136) = 1,506,720	=20x4 = 32	0,6	1,506,805
TOTAL	1,745,122			
SAFE FACTOR 10% and Rounding	1,900,800			

- The conclusion obtained operating fluctuations are as much as 1,900,800 cycles per year. Then it can be ascertained that the component occurs phatic load. The minimum limit for fatigue load is 1,000,000 fluctuations per year [3].

2. Conducting Level 2 and 3 Analysis.

   To perform level 2 and level 3 analysis, finite element analysis must be carried out to determine the greatest stress in the material. Based on the simulation results, the largest voltage was 103.561 psi.

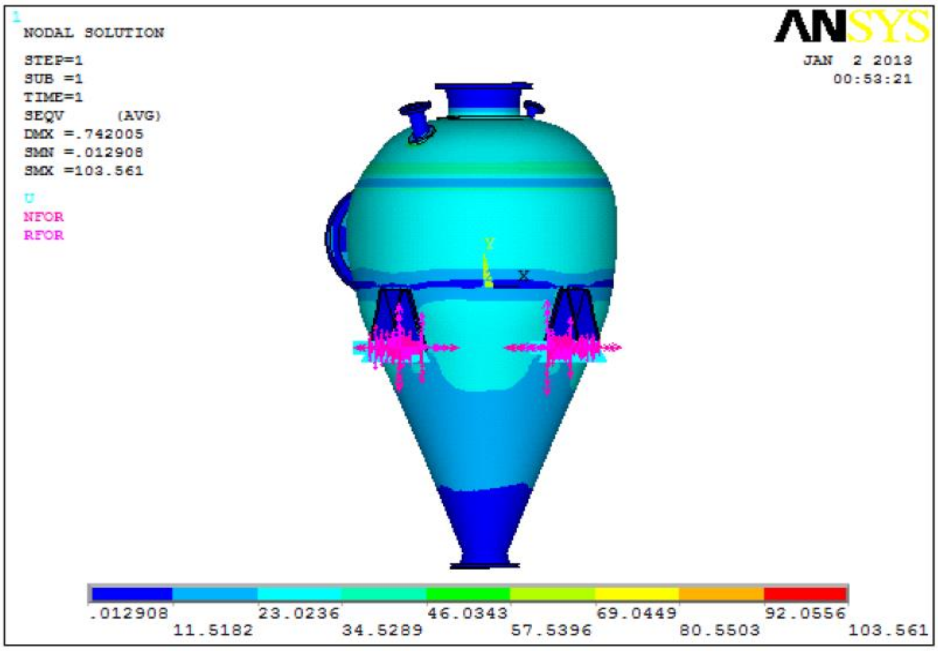

Figure 8. Finite element analysis (FEA) in mixing vessels.

After obtaining the maximum voltage we can find the cyclic load that the component can bear, namely:

- The equivalent force due to cyclic load, S can be found by the equation [2.20] while for the reducing factor due to fatigue (K_f) is 1.5 because the component welds are carried out a grinding process followed by visual inspection, magnetic test and pressure test and fatigue penalty factor ($K_{e,k}$) is 1 because the largest voltage does not exceed 3 times the clearance voltage (103.661 psi < 3x70.000 psi), i.e. :

$$S_{alt,K} = \frac{1{,}5.1.103{,}56}{2} = 77{,}67 \quad MPa$$

- The voltage factor, Y can be calculated by the equation [2.24] while the modulus of elasticity to convert fatigue design (E_{fc}) is 195,000 psi while the modulus of elasticity of the material is 200,133 psi, so the Y value is:

$$Y = \frac{77{,}67}{6{,}894757} x \frac{195000}{200133} = 10{,}97$$

- The cyclic coefficient, X can be calculated by the equation [2.25] , while the fatigue coefficient (C1 to C10) can be known in table 3.F2 ASME VIII-2013 Div.2 so that the cyclic coefficient can be calculated, namely :

$$X = \frac{1{,}61 + (-1{,}02).Y + (0{,}029).Y^2 + (0{,}000386).Y^3 + 0..Y^4 + 0.Y^5}{1 + (-0{,}041)Y + (0{,}00003)Y^2 + (0{,}00018).Y^3 + 0.Y^4 + 0.Y^5} = 7{,}10594$$

Thus, the cyclic load that can be withheld, N is:

$N = 10^x = 10^{7{,}1} = 12{,}762{,}624$ kali.

- It is concluded that the life of the tool is: 12,762,624 / 1,900,800 = 6,71 Years

Hypothesis Testing

To prove the initial hypothesis, it is necessary to simulate several main parameters of the failure mechanism, including variations in corrosion thickness, variations in depth and length of crack defects and variations in pressure and temperature changes in equipment. Here are the results of proving the initial hypothesis:

1. The depth of corrosion can affect the integrity of the jackfruit.

To determine the effect of corrosion depth on tank integrity, corrosion thickness data (x) and integrity value (y) were collected. If you pass FFS levels 1 and 2, the value is 1, but if you do not pass FFS levels 1 and 2, the value is 0. Here are the results of the data obtained:

Table 16. Pearson Correlation Table Based on SPSS Simulation.

Descriptive Statistics

	Mean	Std. Deviation	N
Tebal Korosi	1.17	.912	38
FFS	.95	.226	38

Correlations

		Korosi	FFS
Tebal Korosi	Pearson Correlation	1	-.665**
	Sig. (2-tailed)		.000
	N	38	38
FFS	Pearson Correlation	-.665**	1
	Sig. (2-tailed)	.000	
	N	38	38

**. Correlation is significant at the 0.01 level (2-tailed).

Based on the results above, it can be concluded that: corrosion thickness has a strong correlation with component integrity (FFS levels 1 and 2) with a confidence / significance level of 90%. This is evidenced by a correlation coefficient of -0.665 which means a strong but inverse correlation and a significance of 0.01 which means that the error coefficient is 10%. Thus hypothesis 1 is proven.

2. The depth and length of the rat defect can affect the integrity of the tank.

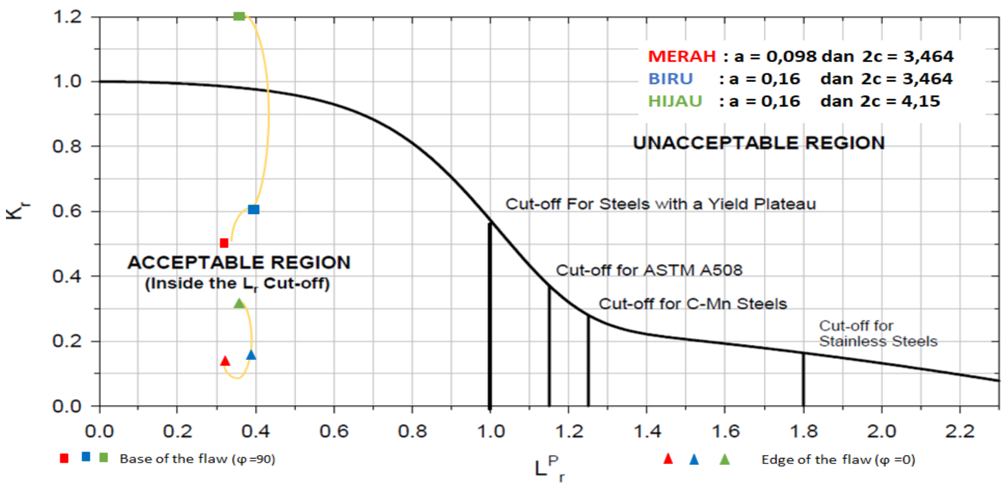

Figure 9. Simulated depth and length of crack defects against FAD

Based on the graph above, it can be concluded that in FFS level 1 and 2 simulations, the clamping and length of crack defects affect the integrity of the tank and the length of crack defects has a more dominant impact than the depth of crack defects. In this case, the research is limited only to a depth of 1/4 plate thickness as required in the FFS level 1 and 2 methods.

3. Pressure and temperature fluctuations can affect the integrity of the tank.

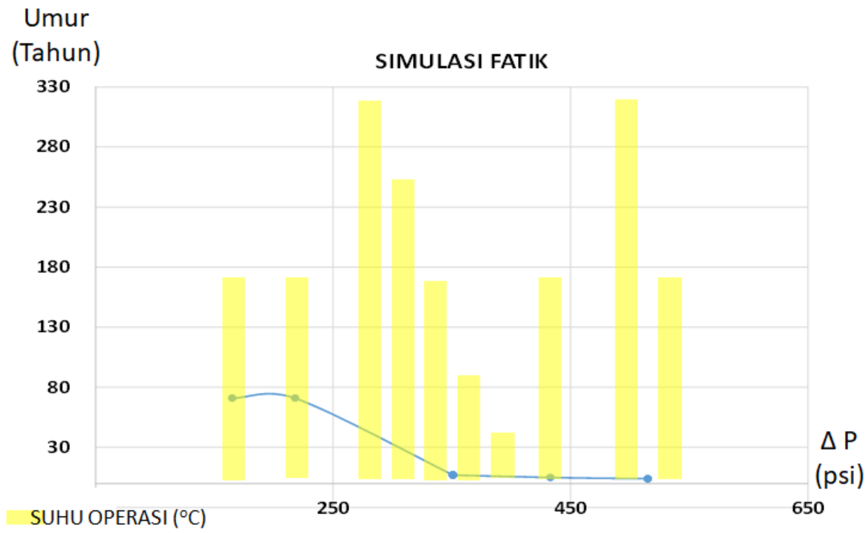

Figure 10. The simulated life of the mixing container is simulated at various changes in pressure (psi) and temperature (°C).

Based on the graph above, it can be concluded that the difference in temperature and pressure will affect the life of the tool, but the most dominant in affecting the life of the tool is pressure.

Conclusion

Based on the description above, it can be concluded that, first, the tanks that pass FFS are: propane tanks, butane tanks, mixing vessels and LPG drums. Tanks that do not pass FFS are solar tanks, therefore the solar tank must be repaired immediately to prevent corrosion from continuing. Second, Factors affecting component integrity are: Thickness of corroded tank plate, depth and length of crack defects and voltage and temperature fluctuations. Third, the application resulting from this study can be used as a reference in conducting FFS feasibility analysis / assessing the integrity of equipment that has been operated. Fourth, the damage mechanism on the tank can be monitored by monitoring the thickness of the tank wall, currently there is crawler technology that can measure the thickness of the plate on the entire tank wall under operating conditions. Some indications that can be obtained by measuring the thickness of the tank wall are: corrosion rate, LTA process and LTA area.

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