CHAPTER 3: CALCULATING CURRENT FITNESS FOR SERVICE AND NEXT INSPECTION INTERVAL OF A TANK SHELL

Activities: Read Chapter 3: CALCULATING CURRENT FITNESS FOR SERVICE AND NEXT INSPECTION INTERVAL OF A TANK SHELL. Watch the Video "INSPECTION INTERVALS FOR TANK SHELLS" and analyze the questions at the end of the chapter. Have Office Excel ready for the calculations.

THIN WALL EQUATION

A tank is very much like a disposable clear plastic water cup. It has a very thin wall and a reinforcement at the top to avoid that the wall is crushed. Tanks can be considered "thin-walled pressure vessels".

A thin-walled pressure vessel is one in which the shell of the vessel has a thickness that is much smaller than the size of the vessel, and the vessel is subjected to internal pressure that is much greater than the exterior pressure

For a cylindrical vessel:

Eq. 10. $S = \frac{pd}{2t}$ Original equation for a thin wall vessel

Eq. 11. $t = \frac{pd}{2S\boldsymbol{E}}$ Rearranging and adding Joint Efficiency

Eq. 12. $t = \frac{\rho gHD}{2SE}$ Replacing pressure with the formula for static pressure in a fluid

Eq. 13. $\rho g = 32.3\ \frac{ft}{s^2} * 1.94\frac{slug}{ft^3} = 62.4\frac{lb}{ft3}$ Replacing density and gravity with their respective values

Eq. 14. $t(ft) = \frac{62.4HD}{2SE}$

Eq. 15. $t\ (ft) = \frac{31.2(H-1)D}{SE}$ adding the one-foot reference point

Eq. 16. $t(in) * 12 = \frac{31.23\rho(H-1)D}{SE}$ putting the left side of the equation in inches, right side still in feet

Eq. 17. $t_{min}(in) = \frac{2.6DG(H-1)}{S_{max}E}$

Where

$D = Diameter\ of\ the\ tank\ in\ feet$

$H = Liquid\ level\ in\ feet$

$S_{max} = Maximum\ allowable\ shell\ stress\ in\ psi$ (Taken from API 650 if the tank is new, or from Table 4.1 of API 653 if the tank is in service)

$E = Joint\ efficiency. Only\ use\ E\ if\ the\ area\ is\ close\ to\ the\ vertical\ weld$

This equation is for 1) new tanks and also for 2) tanks in service.

Now on to the evaluation of different types of metal loss in a tank:

EVALUATION OF TANK SHELL CORRODED AREAS

API 653 evaluates 4 scenarios

1. Localized corrosion close to welds
2. Localized corrosion away from welds
3. Any Interest area
4. Entire shell course

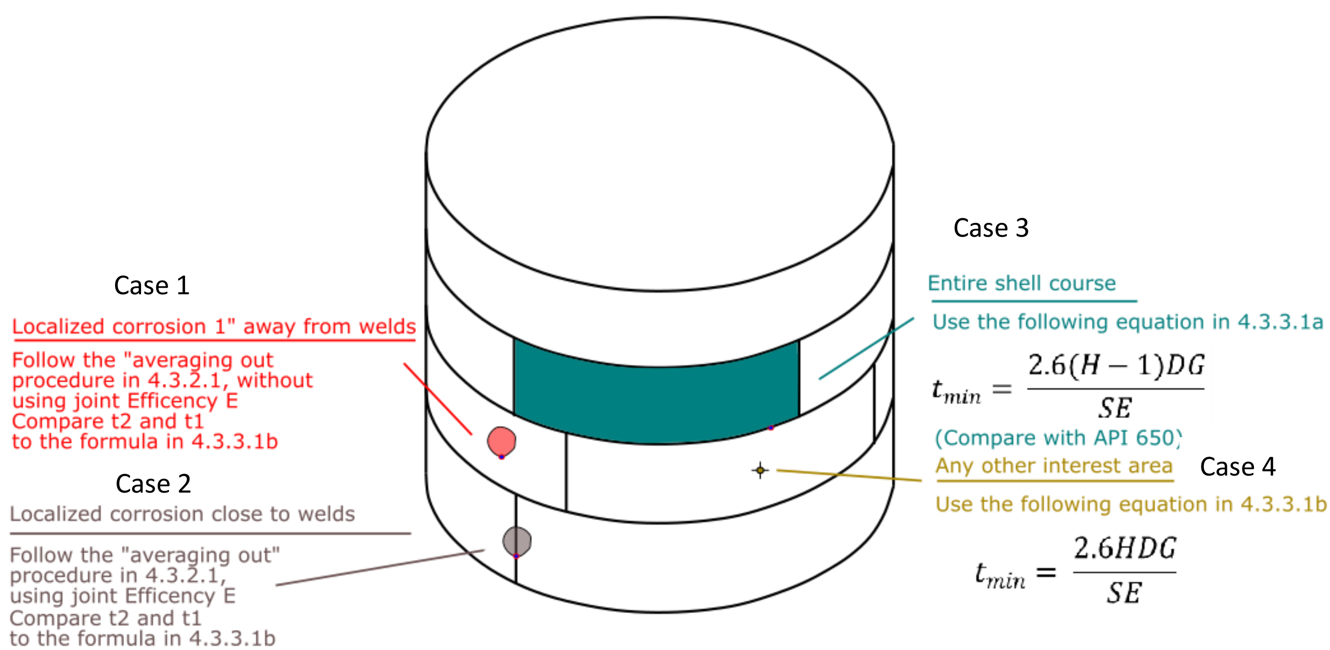

FIGURE 7 HOW TO EVALUATE DIFFERENT PARTS OF TANK SHELLS

EVALUATING CORRODED AREAS OF CONSIDERABLE SIZE (CASES 1 AND 2)

What we are going to do is to dissect the diagram in FIG. 4.1 of API653 until we understand it, and there will be no way we fail any of the questions related to this in the exam. First, check the following diagram.

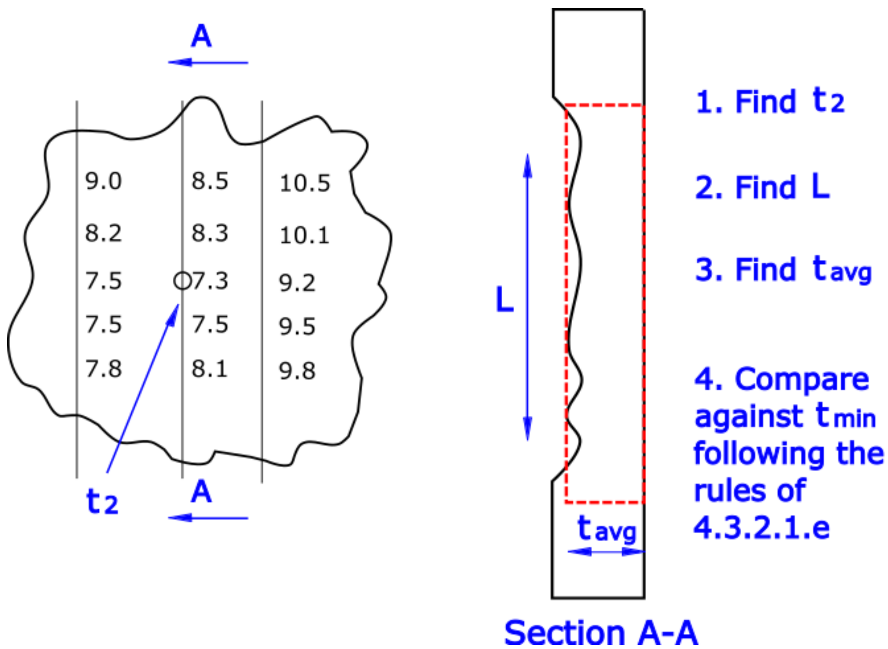

FIGURE 8 BASED OFF 4.1 OF API 653 CALCULATION OF AVERAGE THICKNESS

Look at the vertical sections drawn in the picture which represent hoop stress planes. Remember that hoop stresses (stresses that are tangential to the shell of the tank) are higher in vertical planes than in horizontal planes. I will show you the demonstration later…

Corrosion can affect tank shells in many ways. In time, uncontrolled corrosion can weaken or destroy the tank´s shell, resulting in holes or possible structural failure, and release of stored products into the environment. But the most common form of damage is a "generally uniform loss of metal over a large area or in localized areas".

PROCEDURE FOR AVERAGING CONTROLLING THICKNESSES

In a scheduled external inspection scenario, where you must evaluate a tank shell, you have to follow the procedure of 4.3.2.1. of API 653 and figure 4.1.

For determining the controlling thicknesses in each shell course when there are corroded areas of considerable size, measured thicknesses shall be averaged in accordance with the following procedure.

1. Calculate the minimum thickness t_2 in the corroded area

2. Calculate the critical length L in which thicknesses "average out", with one of the following formulas

Eq. 10. $$L = 3.7\sqrt{Dt_2}$$ (SI)

Eq. 11. $$L = 33.75\sqrt{Dt_2}$$ (USC)

3. Locate L, in several vertical planes that you think are more affected by corrosion, and measure at least 5 points to get t_{avg} in each one of those vertical planes. One of those planes will have the lowest average thickness, which you should compare to t_{min} per the formulas in 4.3.3.1

Eq. 12. $$t_{min} = \frac{2.6(H-1)DG}{SE}$$

for an entire shell course

or

Eq. 13. $$t_{min} = \frac{2.6HDG}{SE}$$

for locally thinned areas

Essentially, this procedure limits the size of the zone you are evaluating so it is not too big. This way the "averaging out" is a more realistic way of evaluating metal loss than the arithmetical average.

4. Compare t_1 and t_2 against t_{min} with the following criteria

i) the value t_1 shall be greater than or equal to t_{min}, subject to verification of all other loadings listed in 4.3.3.5;

ii) the value t_2 shall be greater than or equal to 60 % of t_{min}; and

iii) any corrosion allowance required for service until the time of the next inspection shall be added to t_{min} and 60 % of t_{min}

Corroded areas can be present internally or externally. The inspector needs to be able to see the corroded area to assess which area is more affected by corrosion.

EXAMPLE OF CASE 1. GENERALLY CORRODED AREA *AWAY FROM THE WELDS*

CUI was detected after the insulation of a tank was removed for inspection. It generated a corroded area away from vertical welds, in the bottom of the third course of the tank, which is in operation. The inspector took 5 UT measures along 3 vertical planes each, in the positions where he thought there was more corrosion, following the instructions in API 653, 4.3.2.1.c "*The authorized inspector shall visually or otherwise decide which vertical plane(s) in the area is likely to be the most affected by corrosion*". His findings are illustrated in Fig 1. The product stored is crude oil with a specific gravity of 0.978. Corrosion rate is 0.5*mm/year*. Having in mind the average corrosion measured, is the tank safe to operate until next inspection due in 5 years? D= 15.24m. The third course is originally 12*mm* thick ASTM-A-36M steel. Maximum liquid level is 11.88m and courses are 8ft wide.

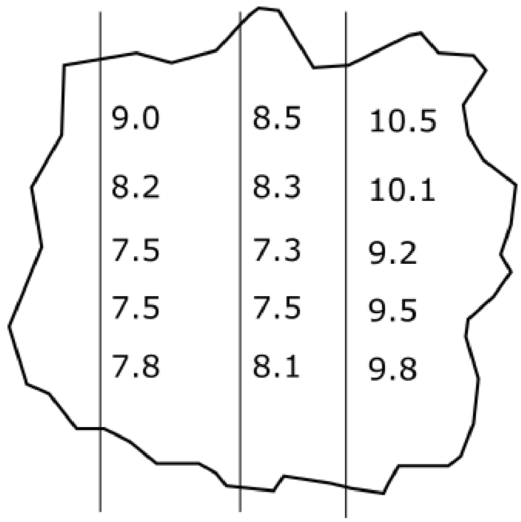

FIGURE 9 UT MEASUREMENTS OF A GENERALLY CORRODED AREA

SOLUTION:

1) Find the controlling thickness

$$t_2 = 7.3mm = 0.287in$$

2) Calculate the critical length

$$L = 33.75\sqrt{Dt_2} = 33.75\sqrt{15.24 * 7.3} = 356mm = 14in$$

3) Calculate t_{avg} along several vertical planes, with at least 5 thickness measures in each plane, and compare against t_{min}

$$t_{avg1} = \frac{9 + 8.2 + 7.5 + 7.5 + 7.8}{5} = 8.0mm$$

$$t_{avg2} = \frac{8.5 + 8.3 + 7.3 + 7.5 + 8.1}{5} = 7.94mm = 0.312in$$

$$t_{avg3} = \frac{10.5 + 10.1 + 9.2 + 9.5 + 9.8}{5} = 9.82mm$$

The lowest average thickness is 7.94mm, in plane #2. Then we calculate t_{min} in USC

$$D = 15.24m = 50ft$$

$$H = 11.88m - 2 * 2.44m = 7m = 22.96ft$$

$$t_{min} = \frac{2.6 * 22.96 * 50 * 0.978}{27{,}400 * 1} = 0.106in$$

Let´s compare with the criteria for continual operation. As API 653 says, the criteria for continued operation is as follows:

i) the value t_1 shall be greater than or equal to t_{min} (see 4.3.3 or 4.3.4), subject to verification of all other loadings listed in 4.3.3.5; t_1 is t_{avg}

Eq. 18. $t_{avg} \geq t_{min}$

$$0.312in \geq 0.106in \quad OK$$

<u>The tank is fit for service.</u>

ii) the value t_2 shall be greater than or equal to 60 % of t_{min} and

Eq. 19. $t_2 \geq 0.6 * t_{min}$01

$$0.287in \geq 0.6 * 0.106in = 0.06in \quad OK$$

<u>The tank is fit for service.</u>

iii) any corrosion allowance required for service until the time of the next inspection shall be added to t_{min} and 60 % of t_{min}

Eq. 20. $t_{avg} \geq t_{min} + CR * interval$

$$CR = \frac{0.5mm}{year} = 0.019inch/year$$

$$0.312in \geq 0.106in + 0.019\frac{inch}{y} * 5y = 0.204in \quad OK$$

<u>The tank is safe to operate until next inspection</u>

$$\text{Eq. 21.} \quad t_2 \geq 0.6 * t_{min} + CR * interval$$

$$0.287in \geq 0.6 * 0.106in + 0.019\frac{mm}{y} * 5y = 0.158in \quad OK$$

<u>The tank is safe to operate until next inspection</u>

This analysis shall be made for as many thinned areas there are in the tank shell. If the corroded region is larger than L (40 inches) in the vertical direction, the region must be divided into multiple sections such that no individual section is larger than L. Each section must then be evaluated separately.

An inspector may want to simply replace shell plates in areas that are larger than 40 inches long.

EXAMPLE OF CASE 2. GENERALLY CORRODED AREA *CLOSE TO THE WELDS*

With the following data, tell if the tank is safe to operate UNTIL THE NEXT INSPECTION:

Joint efficiency is 0,85
Maximum liquid height = 56 feet
Tank diameter = 60 feet
Product specific gravity = 0.978
Course width = 8 feet
Corrosion rate = 0.1 mm / year
Material = ASTM-A-36
A corroded area was observed on the second shell course, at 46 feet from the top. The next interval for inspection is 10 years.
Original thickness of the second shell course = 12,5mm
The vertical weld is located between b and c.
Readings in vertical planes a, b, c, d, in millimeters, over the length L were:

	a	b	c	d
1	10.6	10.3	10.1	10.3
2	10.1	10.1	9.9	9.8
3	10.1	9.8	8.5	9.8
4	9.5	10.1	9.2	10.1
5	10.6	10.3	9.8	10.3
Σ	50.8	50.6	47.5	50.3

SOLUTION:

1) $t_2 = 8.5mm = \ 0.335inches$

2) $L = 3.7\sqrt{Dt_2} = 3.7\sqrt{120 * 0.335} = 23.46inches$

3) t_{avg} for plane a = 50.8/5 = 10.16*mm* = *0.4in*

t_{avg} for plane b = 50.6/5 = 10.12*mm* = *0.39in*

t_{avg} for plane c = 47.5/5 = 9.5*mm* = *0.374in*

t_{avg} for plane d = 50.3/5 = 10.06*mm* = *0.396in*

So, the weakest plane is c. And the lowest of t_{avg} is 0.374in

$t_{avg} = 9.5mm = 0.374in$

4)

$$t_{min} = \frac{2.6 * 60 * 46 * 0.978}{24{,}900 * 0.85} = 0.331in$$

Criteria for safe operation until next inspection:

$$t_{avg} \geq t_{min} + CR * interval$$

$$0.374in \geq 0.331in + 0.0039\frac{in}{y} * 10y = 0.370mm \quad OK$$

The tank is NOT safe to operate until next inspection.

$$t_2 \geq 0.6 * t_{min} + CR * interval$$

$$0.334in \geq 0.6 * 0.331in + 0.0039\frac{in}{y} * 10y = 0.237in \quad OK$$

<u>The tank is safe to operate until next inspection.</u>

UT MEASUREMENTS OF A TANK SHELL FOR EVALUATING ENTIRE SHELL COURSES

Usually, 4, 6 or 8 axis measurements of shell thickness are taken in several vertical lines comprising 360° in each course of the tank shell to fulfill the UT requirements of external inspection. When using a tank crawler, usually you measure every foot on eight lines in the eight wind directions in the tank shell. This can be modified depending on the configuration of the tank.

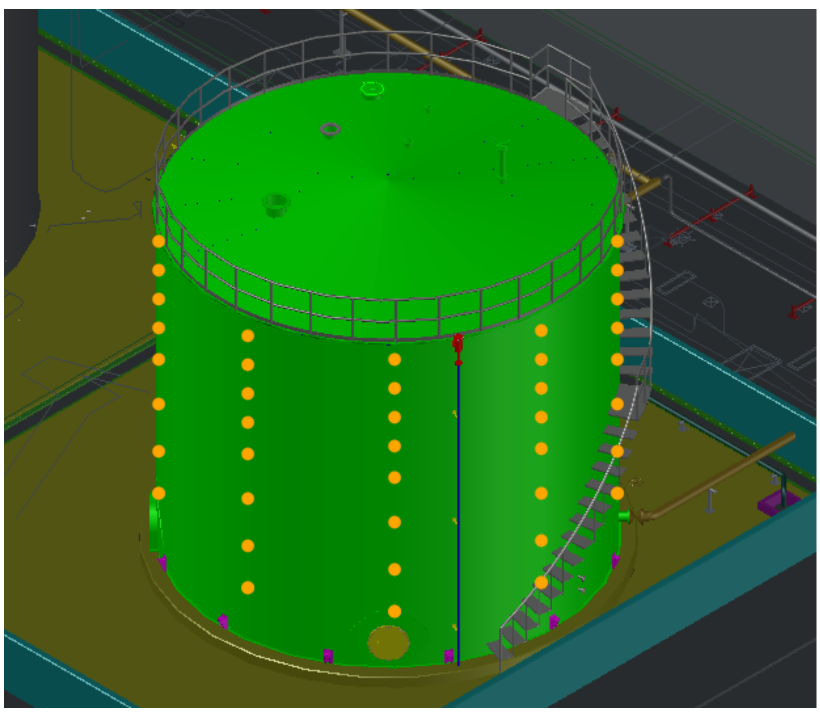

FIGURE 10 UT MEASUREMENTS OF A GENERALLY CORRODED AREA

EXAMPLE CASE 3. ENTIRE SHELL COURSE

Check if this tank is fit for service

Maximum liquid height = 33.8 feet
Tank diameter = 40 feet
Product specific gravity = 1
Course width = 6 feet
Material = ASTM-A-283 Gr C = 23600psi for the first 2 courses and 26000 for top course

The following data for the thickness of the shell was measured using a crawler

	t_{last}
Bottom course	0.237in
Second course	0.239in
Third course	0.192in
4th course	0.170in
5th course	0.169in
6th course	0.165in

SOLUTION

The minimum allowable thickness for each course is calculated using the following equation

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

MINIMUM ALLOWABLE THICKNESS CALCULATION		Suitable $t_{last} > t_{min}$
Bottom course	$t_{min} = \frac{2.6(33.8-1)*40}{23600} = 0.144in$	YES
Second Course	$t_{min} = \frac{2.6((33.8-6)-1)*40}{23600} = 0.118in$	YES
Third and top Courses	$t_{min} = \frac{2.6((33.8-12)-1)*40}{23600} = 0.0832in$ then $t_{min} = 0.1in$	YES

EXAMPLE CASE 4. ANY OTHER INTEREST AREA

During inspection of a tank, an indication was found in the shell adjacent to the shell-to-bottom weld on the inside, with a depth of 4mm /0.157in (See picture 1). The following is the data for the tank.

Diameter: 100ft
Liquid Level: 43ft
Shell material: A36
Service: Crude
Nominal thickness of the bottom course: 0,5inch

PICTURE 1. LACK OF MATERIAL IN THE SHELL ADJACENT TO THE SHELL-TO-BOTTOM WELD. CASE 4 (ANY OTHER INTEREST AREA)

Engineering judgment states that this plate is suitable for service, because the tank had many years in service like that. However, the gap was fill-welded because the measured thickness was below the minimum thickness. Explain Why?

SOLUTION

The minimum allowable thickness for the gap is calculated using the following equation

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

Then

$$t_{min} = \frac{2.6 * 43 * 100}{24900 * 1} = 0.448in$$

But

$$t_{last} = 0.5in - 0.157in = 0.342in$$

$t_{last} < t_{min}$ then the tank is not suitable for service. The gap must be fill-welded

WHAT TO DO IF YOUR TANK IS NOT FIT FOR SERVICE

If the minimum thickness "t_{min}" calculated is less than needed for the tank to continue providing service, then one of three things should be made

- the corroded or damaged areas shall be repaired, or
- the allowable liquid level of the tank reduced, or
- the tank retired

POINTS TO REMEMBER

You shall evaluate the shell for continued operation solving the equation in 4.3.3. If it doesn´t fulfill the equation, damaged areas should be repaired, or the inspection interval reduced, before the tank continues to work.

ADDITIONAL INFORMATION: WAYS OF REPAIRING A SHELL

Thin areas in the shell can be repaired by fill-welding (Picture 2), or by welding patch plates over the shell, inside or outside (Pictures 3 and 4).

PICTURE 2. FILL-WELDING THIN SPOTS IN THE SHELL.

PICTURE 2. TOMBSTONE LIKE LAPPED PATCH PLATES WELDED IN THE INSIDE OF A TANK SHELL. THE PATCHES ARE BIGGER THAN ALLOWED BY API 653. IT WORKS, ANYWAY.

Picture 2. LAPPED PATCH ON THE SHELL, NEXT TO THE ROOF. OTHER CORRODED AREAS CLOSE TO THIS PATCH WHERE FILLED BY WELDING

.

If you don´t understand the complicated mathematical equations, that´s OK, don´t worry. That´s typical and only temporary