CORROSION EFFECTS AND RATES IN OIL FIELDS STORAGE TANKS

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DOI< 10.26821/IJSHRE.8.9.2020.8907>

ABSTRACT

Corrosion is in essence a statistical effect governed by a number of variables. microscopic variations in a surface tend to cause different forms of corrosion and also variations in the corrosion rate over either a wide or small area (pitting). In these areas the simple assumption that corrosion rate is uniform across an area is unlikely to be accurate, and sample thickness measurements are unlikely to be representative of the whole component.

The corrosion effect on the operability and serviceability of bottom plates of a steel aboveground storage tank, the effect which is considered to be a serious threat to the tank structural integrity. In this study the data of the analysis are collected as a readings of thickness through all the area of the tank bottom, processed statically and shows that the critical thickness profile represented by an averaged value for thickness could be reliably taken to consideration for further analysis through finite element when the COV is less than 10%, The finite element analysis result concise with the results of basic design limits.

Keywords: Corrosion, Corrosion Rate, Oil Storage Tanks, Metal Loss, Stress Analysis

1. INTRODUCTION

Corrosion has been shown to be the cause of 15-20% of leakages of hydrocarbons from offshore plant. Leakages can lead to more disastrous consequences if subsequent ignition was to result in fire or explosion. In order to reduce the number of leakages from this source, the defects that lead to failure need to be detected and mitigating action taken before failure occurs. The

refinery products containing mixtures of straight-chain and branched chain hydrocarbons, alkenes, naphthalene's, aromatics, and other compounds Oil derivatives should not be corrosive to metals. The accumulation of water at the bottom of storage tanks is a primary prerequisite for development of corrosion. Generally, it is extremely difficult to avoid the presence of water in tanks. The basic sediment and water (BS&W) content in storage and transport facilities is usually limited to 0.5 volume percent [1]. However, water and water vapors may ingress storage, transportation, and some other operations [2].

Because of the high polarity of water molecules, the water drops separate from the organic phase on the steel surfaces forming a water pillow at the bottom of the tanks and electrochemical corrosion of steel takes place. Processes of bottom corrosion may proceed even more intensively due to upper inflow of oxygen into the tanks [3]. The solubility of oxygen in hydrocarbons is higher (60 to 70 ppm) than in water (8 ppm). Therefore, oxygen diffuses from the organic phase (hydrocarbons or fuel) to the water phase according to the solubility in each phase, and the concentration gradient increases up to oxygen saturation in the aqueous phase [3].

Concentration cell corrosion may occur when a surface deposit, mill scale, or crevice creates a localized area of lower oxygen concentration [4]. The difference in oxygen concentration between the inaccessible area and the bulk electrolyte creates a concentration cell and may result in significant localized metal loss.

The extent of internal corrosion is also influenced by the temperature, CO₂, H₂S and salts (sodium chloride, calcium chloride, and magnesium chloride), light organic

acids, etc. In storage tanks, the aggressive variables undergo diversion from organic phase into the aqueous phase and may cause a decrease in the pH and increase in the water corrosivity. Even when some biotic corrosive factors are absent, the bacteria are known to cause severe internal corrosion problems in oil storage and transport [5].

Ability of micro-organisms to live and make colonies in both the water phase and the inter-phase of water/hydrocarbon, as well as the generation of their metabolism products which made the physical and chemical properties of the stored product worse.

Activity of microorganisms promotes an increase of suspended solids content and formation of corrosive sludge at the bottom of tanks. Microbial degradation of HCs and other organic compounds increases the water content in sludge, which can exceed 10%. Pitting corrosion has been observed underneath sludge deposits that are a mix of sand and clay particles, water, and product [1].

Another corrosion formation Scenario occur on the bottoms of tanks by the flushing operation when the stored product is intended to be replaced with another different, the adopted procedure is to use the sea water for lines flushing due to repeated, frequent pitting between the solids in the flushing water and the surface of the bottom which in turn, scratches and removes any protective layer and a rust scale formed on the bottom surface.

As loading /unloading processes proceed corrosion at the location on the floor plates spreads where the coating and/or any protective rust scale has been damaged. In some cases, the welding processes produce variances in the microstructure of the steel bottom plates which impact in a galvanic corrosion as a result occur at the heat affected zones (HAZ) of the base near the weldments locations.

2. CORROSION IN OIL STORAGE TANKS

Corrosion is in essence a statistical effect governed by a number of variables. For example, microscopic variations in a surface tend to cause different forms of corrosion and also variations in the corrosion rate over either a wide or small area (pitting). In these areas the simple assumption that corrosion rate is uniform across an area is unlikely to be accurate, and sample thickness measurements are unlikely to be representative of the whole component.

Studies and applications of the statistical nature of corrosion and its relationship to inspection, have been carried out since the 1950's, but have never been commonly applied in routine inspections. No standards exist for the analysis of inspection data for corrosion.

Initial work using extreme values was carried out by Gumbel [6]. He used the theory to estimate the condition of pipelines with external corrosion.

Manley [7] described the use of an ultrasonic thickness gauge, and a computer, to log and record data from an erosion/corrosion survey. Essentially the method used was linear interpolation of sample readings.

Joshi et al [8] used the extreme value analysis method to extrapolate from small inspection patches in an above ground storage tank to the whole tank. They noted that the method particularly applied to pitting corrosion. Sparago [9] showed how the underlying thickness distribution can be used to estimate the probability of a wall thickness being below a certain level from ultrasonic thickness gauge data.

Kawaka [10] gave a useful overall text to the statistical method of analyzing corrosion data. The use of these methods for analyzing corrosion data has been referred to consistently in Japan since the 1980's, however little of the work refers to the strategies of data collection by NDT methods.

More recently Mitsui Babcock [11] conducted a group sponsored project which included some analysis of corrosion data by the extreme value method.

Thus it can be seen that although the statistical methods have been developed, the application of these methods is not carried out routinely apart from possibly in Japan. The works above, although describing the methods used, do not generally validate the results obtained by comparing a sample with the whole population.

3. REQUIRED DATA FOR CHARACTERIZING METAL LOSS

Several non-destructive techniques are available to inspect the extent of the metal loss/leakage in tanks and pressure vessels. The choice depends upon the material, type of flaw, access to surface, availability, cost, etc. Some of the inspection techniques used in the process industry are visual examination, magnetic particle testing, radiographic testing, ultrasonic testing, acoustic emission testing and thermography. Fitness for service assessments for wall thinning cannot be performed from thickness measurement at a single sample point. Usually ultrasonic thickness readings are measured in a grid with a minimum

spacing equal to twice the nominal wall thickness of the vessel [12].

The region of metal loss can be characterized by two thickness measurement techniques, namely point thickness reading (PTR) and critical thickness profile (CTP). PTR is random sampling of thickness measurement that can be used only if the variation in thickness readings is statistically small. The variation in the thickness reading is expressed using Coefficient of Variation (COV), which is defined as the standard deviation of a sample divided by the mean of the sample, mathematically:

$$COV = \text{Standard Deviation} / \text{Mean} \quad (1)$$

The CTP is established using thickness reading from a measurement grid with suitable interval to allow for accurate characterization of the metal loss. For most of the pressure vessels and pipe lines, the CTP should be established in both the meridional (longitudinal) and circumferential directions following the geometry profile. But for atmospheric tanks, only the CTP along the meridional direction is required by the standard and hence the meridional inspection planes are sufficient. The circumferential inspection planes are not required because the stress in the direction normal to the hoop is considered negligible and does not govern the design thickness calculation [13] [14].

3.1 FINITE ELEMENT MODEL

2D Model drafted by ANSYS in 2D environment to represent the tank geometry with a full definition of forces acting on bottom and shell of the tank in addition to the consideration of the bottom to be fixed from the underneath since it actually anchored to the concrete ring base with a countersunk bolts.

Table (1) in the appendix [1] shows the oil tank geometry dimensions and different thickness. Figure (1): quarter segment illustrates the distribution of force on the shell and the bottom plates.

4. RESULTS and DISCUSSIONS

4.1 Ultrasonic Test

The ultrasonic test carried out to determine the thickness through all the flooring area of the tank and so depict a clear image about how it look and allow for further evaluation.

The following graphs summarize the results readings of 261 readings of all the area of the tank bottom for both TK-8 and TK-7 with a trend line slope equation of:

For TK-8

$$y = 0.0014x + 4.9062 \quad (2)$$

For TK-7

$$y = 0.0002x + 4.1029 \quad (3)$$

Figure (2): the thickness through all the flooring area of the tanks

Figure (3): the thickness frequency for tank (8)

Figure (4): the thickness frequency for tank7

Figure (5): normal distribution for the thickness frequency for tank7 and tank8

	TK-8	TK-7	Percentiles	TK-8	TK-7
Mean	5.091	4.123			

Std. Error of Mean	0.03351	0.05898	10	4.3	2.9438
Median	5.0569	4.0760	20	4.7	3.207
Mode	5	4	25	4.7	3.3682
Std. Deviation	0.501	0.95292	30	4.9	3.5644
Variance	0.293	0.908	40	5	3.9149
Skewness	0.07	0.01	50	5	4.076
Std. Error of Skewness	0.151	0.151	60	5.2	4.3443
Kurtosis	-0.395	-0.591	70	5.3	4.7022
Std. Error of Kurtosis	0.3	0.3	75	5.5	4.8708
Range	2.3	4.3	80	5.6	5.0113
Minimum	4	2	90	5.9	5.31
Maximum	6.3	6.3			
Sum	1328.76	1076			

Table (2): statistical analysis for thickness of TK-7 and TK-8

4.2 COEFFICIENT OF VARIATION

As from equation (1), and the data from table (2) taking the mean as (5.091) and the standard deviation as (0.501) substituting this values the following resulted:

$$\text{For } \text{COV}_{(\text{TK-8})} = \frac{0.501}{5.091} = 0.098409$$

$$\text{For } \text{COV}_{(\text{TK-7})} = \frac{0.952}{4.123} = 0.2309$$

A comparison between the results of the COV for TK-8(0.098409) which fall below the governing limit and TK-7 (0.2309) of give indication that the corrosion behavior for tank 8 fall below the governing limit of 10% and the average of the measurements of thickness for the 261 reading (**5.091 mm**) is considered homogenous (critical thickness profiles) and acceptable for using it for any calculation of thickness involving a reference value, whereas the case for tank 7 the COV value is much beyond that of acceptance accordingly the

readings of the thickness were not considered for further processing.

5.3 CORROSION RATE

The corrosion rate per year was determined using the equation (4)

$$\text{Corrosion Rate} = \frac{\text{Original Thickness} - \text{Av. measured thickness}}{\text{Number of Years}} \quad (4)$$

Considering the original thickness of 8mm and average measured thickness of 5.1 and 4.1 for TK8 and TK-7 respectively the rate will be 0.145 mm. year⁻¹ for 20 years for TK-8 and 0.195 mm. year⁻¹ for TK-7.

Also in case of considering the corrosion occur in faster rate i.e. the corrosion starts to occur after the deterioration of the protective coating layer due to scratching until it's removal within a period of 3 to 5 years then the rate will be 0.193 mm. year⁻¹ for TK-8 and 0.390 mm. year⁻¹, these rates generally were accepted since the average literature value for corrosion rate of gas oil tanks is equal to 0.5 mm year⁻¹, diesel oil tanks is 0.5 mm year⁻¹ and fuel oil tanks is 0.28 mm year⁻¹. Table (3) in appendix [2] and figure (6) give the gradual corrosion rate over 20 years of equal inspection periods of 5 years for TK-8. The tracing of the corrosion over years it could be clearly observed that the rate is negligible in the first five years, then tend to increase slightly through the next five years after that it increased in a greater and almost stable manner for the next inspection intervals, and this might accepted and explained as the original thickness of the plates treated with a protective coating that's scratched till totally removed as the tank in service.

The thickness of bottom accordingly might determine depending on this results and a linear trend equation formulated as:

$$y = -0.1605x + 8.428 \quad (5)$$

Where y represents the value of thickness for a specific year and x stands for the specified year.

When repeating the same for TK-7 the equation will be:

$$y = -0.201x + 8.6842 \quad (6)$$

Equations (5) and, (6) could be used for predicting the average of the thickness for any future thickness determination with a precise results considering the reference of the trend lines for the described tank.

Figure (6): gradual corrosion rate over 20 years of equal inspection periods of 5 years for TK-8.

(a)

(b)

(c)

(d)

Figure (7) contains (a,b,c and d) for stress analysis for different thickness (8, 4.1, 2.7mm) TK-8.

5. CONCLUSION

The corrosion effect on the operability and serviceability of bottom plates of a steel aboveground storage tank, the effect which is considered to be a serious threat to the tank structural integrity. The data of the analysis are collected as a readings of thickness through all the area of the tank bottom, processed statically and shows that the critical thickness profile represented by an averaged value for thickness could be reliably taken to consideration for further analysis through finite element when the COV is less than 10%,The finite element analysis result concise with the results of basic design limits, additionally it predicts the spots of stress concentration , which are all used to weight between complete replacement for the bottom plate and partial repair alternative which considered the most weighted compared to the full replacement with a cut-off of repair costs to 52%, minimizing the downtime to 44.4%, and the rate of return reduced to 49.2%.

APPENDIX

Table (1): Oil tank geometry dimensions and different thickness

Nominal diameter of tank, D		=	24,380	mm
Total height of tank shell, H_t		=	12,000	mm
Maximum design liquid level, H		=	12,000	mm
Design specific gravity of liquid, G		=	1	
Total weight of tank shell, W_s	@59,456 kg	=	583,273	N
Total weight of tank roof, W_r	@5,260 kg	=	51,596	N
Total weight of tank contents, W_p	@5,601,941 kg	=	54,955,041	N
Total weight of tank bottom, W_f				
Case 1	Thickness 8 mm	@29,115 kg	=	285,621 N
Case 2	Thickness 5.091 mm	@20,822 kg	=	204,264 N
Case3	Thickness 4.123 mm	@16,740 kg	=	164,212 N
Case 4	Thickness 2.7 mm	@11,024 kg	=	99,211 N
Case 5	Thickness 1.7 mm	@6,941 kg	=	68,088 N

Thickness (mm)	Type	Total Deformation	Equivalent Elastic Strain	Maximum Principal Elastic Strain	Minimum Principal Elastic Strain	Equivalent (von-Mises) Stress	Maximum Principal Stress	Minimum Principal Stress
8	Min	0. m	2.68e-11 m/m	-3.15e-10 m/m	-1.01e-5 m/m	5.357 Pa	-3.04e+5 Pa	-2.28e+6 Pa
	Max	1.55e-5 m	9.59e-6 m/m	3.79e-6 m/m	-2.59e-11 m/m	1.91e+6 Pa	66100 Pa	9.9074 Pa
6	Min	0. m	1.32e-11 m/m	-2.88e-10 m/m	-1.01e-5 m/m	2.629 Pa	-3.048e+5 Pa	-2.29e+6 Pa
	Max	1.55e-5 m	9.63e-6 m/m	3.80e-6 m/m	-7.78e-12 m/m	1.92e+6 Pa	67717 Pa	2.7426 Pa
5.1	Min	0. m	9.53e-12 m/m	-2.64e-10 m/m	-1.01e-5 m/m	1.91 Pa	-3.027e+5 Pa	-2.28e+6 Pa
	Max	1.55e-5 m	9.59e-6 m/m	3.79e-6 m/m	-2.99e-12 m/m	1.91e+6 Pa	67011 Pa	1.0461 Pa
4.1	Min	0. m	3.13e-12 m/m	-2.19e-10 m/m	-1.01e-5 m/m	0.6256 Pa	-3.026e+5 Pa	-2.28e6 Pa
	Max	1.55e-5 m	9.58e-6 m/m	3.78e-6 m/m	-9.42e-13 m/m	1.91e+6 Pa	67394 Pa	0.57296 Pa

2.7	Min	0. m	9.377e-14 m/m	-1.40e-10 m/m	-1.01e-5 m/m	1.05e-2 Pa	-3.005e+5 Pa	-2.27e+6 Pa
	Max	1.54e-5 m	9.562e-6 m/m	3.77e-6 m/m	-1.64e-14 m/m	1.91e+6 Pa	67267 Pa	2.17e-2 Pa

Table (3): gradual corrosion rate over 20 years of equal inspection periods of 5 years for TK-8

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