Structural Integrity of Fuel Storage Tanks

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***Abstract*— Fuel storage tanks like other utilities in the oil industry are subjected to corrosion due to their content, operation conditions, and environment. Corrosion has a big impact on the integrity of the storage tanks leading to failure of the tank bottom plate and tank shell. The consequences of corrosion damage are fuel leak, tank damage and risk of fire, as well as environmental risks. The aim of this work is to investigate the actual condition of the tank internal shell, bottom plates, and to identify the cause of failure. It investigates the structural integrity of heavy fuel tanks through internal and external inspections for the tank. Visual inspection coincides with ultrasonic thickness measurements are carried out. Microstructure analysis are also conducted for the corroded areas. The results showed that the bottom plate was attacked by a severe pitting corrosion in the center of the tank with a massive loss of the plate thickness. The pittings observed were of various depths and sizes that scattered on localized areas where some of them having thorough holes. Several corrosion mechanisms could occur concurrently or separately. The inspection interval should be rescheduled and may be lowered to two years as the study revealed due to high corrosion rates which was calculated based on 25 years period.**

Keywords*— *Corrosion failure, fuel storage tanks, Structural integrity.

I. Introduction

Corrosion failure of heavy fuel storage tanks is widely encountered in oil industry. There are many reasons for these fuel tanks to be attacked by corrosion phenomenon. Tanks are exposed to corrosive conditions when felt with fuel, and when they are empty the moist atmosphere maintains, as well as repeated heating and cooling. Areas associated with high stresses such as fillets, shell or plate irregularities, welded areas, as well as large surface of the tank can also be the cause. Heavy fuel storage tanks are suffering from heavy corrosion attack particularly at the bottom of the tanks causes a significant leak. The consequences of this spill are loss of fuel, tank damage risk of fire, and environmental risks. The corrosion of oil storage tanks is based on the electrochemical reaction between metal surface and environment, causing metal oxidation and destruction of the tank [1]. It is observed that low corrosion rates are associated with the part of tank being in contact with oil, while higher corrosion rates are associated with the part of tank bottom where the deposited water is present on the bottom surface [2].

Reference [3] introduced the extreme value statistical analysis method when inspection results on small selected areas can be transferred to the whole tank areas in above ground storage tanks. They showed that there is no need to examine the whole tank since the thickness and maximum pit size can be accurately estimated by the extreme value tool. Reference [4] reported that the underlying thickness distribution can be used to estimate the probability of a wall thickness. The failure of oil storage tank due to crack in the fillet weldment between the reactor shell and annular plates was investigated [5]. Failure analysis showed that the initial cracks were generated by corrosion, however, stress concentration was the cause of the propagation of the final failure. Reference [6] reported that the rate of soil side corrosion in the above ground oil storage tank bottoms was an extremely high in the order of 1mm/year. Despite an impressed current cathodic protection system was implemented, corrosion on the external side of the bottom plates was taking place [7].

It is shown that the bottom of the tank has high corrosion in the form of pitting, consequently through holes are formed [8]. This could be due to the residual water in the crude oil which forms a film of oil precipitation at the bottom of the tank. Reference [9] examined corrosion mechanisms of the internal side of the bottom of the crude oil tank. Corrosion mechanisms based on deposited water, hydrogen sulfide and carbon dioxide, sulfate reducing bacteria, were examined. It is shown that despite of using the impressed current cathodic protection system for the external surface of the tank bottom of oil storage tanks, deficiency of protection was proven. This is because of the separation occurred between the electrolyte and the entire surface, so current discontinuity preserves. This may occur as a result of bottom installation consequences such as welding that causes distortions leading to some bottom areas no longer rest directly on the ground, obstructing the current required for the protection [7].

The aim of this work is to investigate the integrity of the Aboveground Storage Tanks (AST), particularly, corrosion related damage. This is performed by tank inspection, analysis of corrosion damage, thickness measurements, and corroded sample examinations. Various engineering techniques are implemented in order to investigate and analyze the problem considered.

II. Structual Integrity of the Tank

A. Tank Specifications

The fuel oil tank under inspection has the specifications illustrated in Table (1).

TABLE I. Tank specifications

Description	Fule oil Tank
Medium	Fuel oil
Tank type	Fixed roof
Designe Code	API-620
Material “ bottom Plates	A 283 Gr.C
Design thickness	7.95mm
C.A corrosion allowance	1.25mm
Full thickness	9.20mm
Material	A 283 Gr.C
Design Temp	90c°
Nominal Capacity	2619 m³
Diameter	15.24 m
Height	14.361 m
Empty Wight	87280 kg

B. Tank Foundation (concrete ring)

A severe cracking damage was observed along the tank concrete foundation ring as shown in Fig. 1. The cracked area showed traces of leakage of fule oil. Massive cracked area was also observed around the tank associated with fule oil lekadge.

Fig. 1 Cracked concrete foundation ring of the tank.

C. Shell of the Tank

The external side of the shell was subject to svere corosion on the low level at the weld joint where the steel wall shell toughes the conceret ring as shown in Fig. 2. Howevere the above part of the shell was almost free of any sign of corrosion. this could be a result of crevice corrosion taking place since the sealing component is not installed (annular ring to foundation). Through the gap btween the annular steel ring and the concrete foundation ring shows possability of mositure entering underneat.

Fig. 2 The external side of the shell svere corosion

D. Bottom Plate (internal & external)

Visual inspection performed showed the presence of large thick layer of a cumulated sludge on the underneath surfaces, especially at the west side of the tank as shown in Fig. 3. Thus sand blasting was conducted to clean the bottom surface of the tank.

Fig. 3 The underneath thick sludge layer.

The inspection showed severe localized pitting corrossion attack with different depths and sizes scattered on localized areas of the internal bottom plate, as shown in Fig. 4.(a).(b). Maximium average areas of localized pitting was 30cm in diameter with a count of 100 pits in avrage, depth average of 2.51mm, with the deepest pit was 7mm. Thorough holes were also observed in middle of tank plate and some ring bottom plates. While, the internal surfaces of some plates away from the center were free from any significant of corrosion (nearly clean surfaces) as in Fig. 5. Considerable reduction in thickness was observed for the bottom plate as shown from the side section of the thickness in Fig. 6.

(a)

(b)

Fig. 4. a) Bottom plate with thorough holes, b) Bottom plate with localized pitting corrosion.

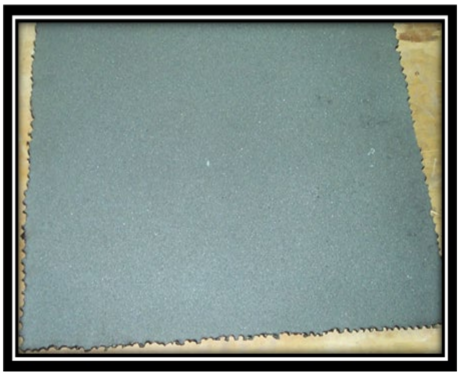

Fig. 5 The free corrosion internal surface.

Fig. 6 Side section of the thickness for bottom plate.

E. *Thickness Measurments and Corrosion Rate for Tank Bottom Plates*

Ultrasonic testing for thickness measurments have been carried out in order to evaluate the tank bottom thickness condition and to evaluate the remaining average thickness for areas of reduction. Thickness readings for different loctions were taken for the tank bottom and found that thickness varies from plate to another, for middle area of the tank and away from the center as illustrated in Figs. 7 and 8. The readings showed a huge reduction in thikness in the centeral area where fuel sludge covered the surface and a through hole was observed. Bottom plate thickness loss at the middle location shows a significant variation, which is out of the acceptable criteria (minimum thickness). This is because of the central area was attacked by localized pitting corrosion. However, the variation in the bottom plates thickness at location away from the center of the tank is consistent, and the loss of thickness is within the acceptable levels. This occurs due to exposed surface was subjected to slow uniform corrosion.

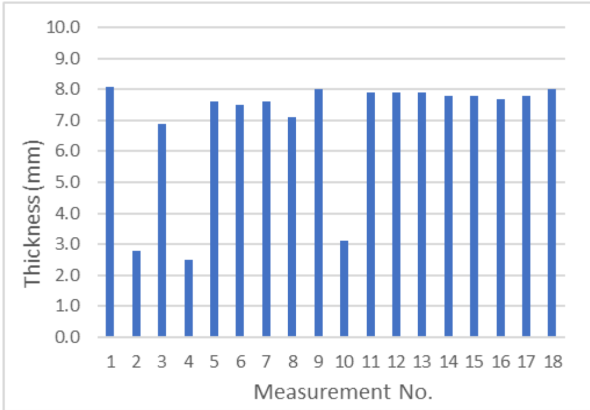

Fig. 7 Thickness measurments for several locations in the center of the bottom plate.

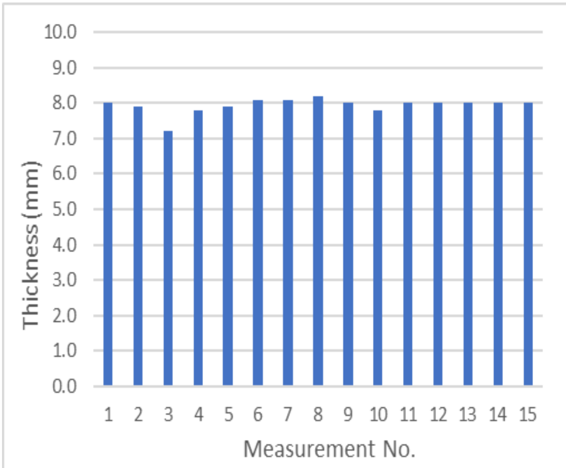

Fig. 8 Thickness measurments for several positions away from the center.

The corrosion rate (CR) was estimated by the formula: CR = (to – ti)/T, where CR = corrosion rate, in mm per year; t_0 = Original thickness (mm), t_i current thickness after (T) years of service, and T = service period of the AST that is 25 years. The minimum acceptable tank bottom plate thickness has to be calculated according to American Petroleum Institute (API) standards 653. The maximum obtained loss of thickness was 6.5mm (only 1.4 mm remaining thickness), and the obtained related corrosion rate (CR), was 0.264 mm/y which seems to be very high corrosion rate according to National Association of Corrosion Engineers (NACE) specification. Other corrosion rates are also determined according to thickness loss based on high loss, average thickness loss, and low thickness loss as shown in Fig. 9. It is noted that the inspection interval should be shortened to two years based on the maximum corrosion rate determined (CR=0.264 mm/y), by considering the minimum remaining thickness (MRT) taken as 50% of the design thickness.

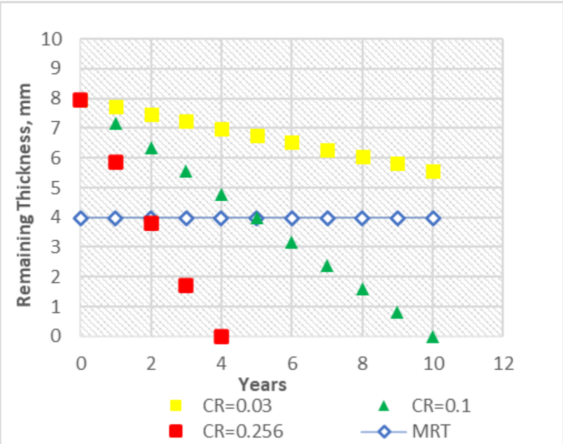

Fig. 9 Various corrosion rate for the tank bottom.

F. *Microstructure of Corroded Samples*

To examine the microstructure, samples with size of 20x20mm were cut from the bottom plate of the tank at different locations from both sides. The samples were initially polished, then etched in 2% Nital solution. The microstructure of the etched metal sample was performed using an optical microscope. The microstructure of the sample X1 that does not contain corrosion is shown in Fig. 10. While corroded sample X3 is shown in Fig. 11. Both samples were inspected by an optical microscope.

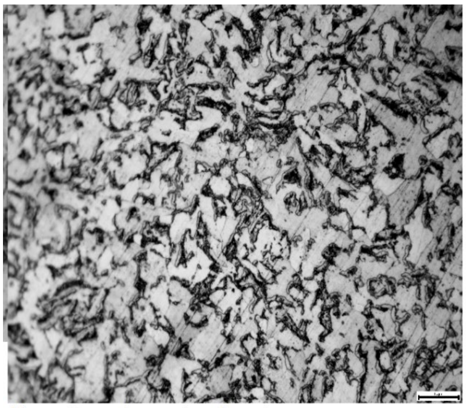
X1 external bottom plate not underneath corrosion

Fig. 10 Free corrosion sample.

The microstructure is composed of ferrite phase and pearlite phase, ferrite (α) is pure iron, and the pearlite is a fine mixture of ferrite and cementite in the lamellar form. The change in the microstructure is observed with an increase in the percentage of ferrite and a decrease in the pearlite areas as shown in the microscopic structure of sample X3 in Fig. 11. It can be the bacterial cells preferentially attached to the grain boundaries are the active points where corrosion typically starts and pearlite which is rich in carbon. The grain boundary is a region of high atomic disorder and this makes it energetically easier for impurities to concentrate at these sites compared to the grain itself.

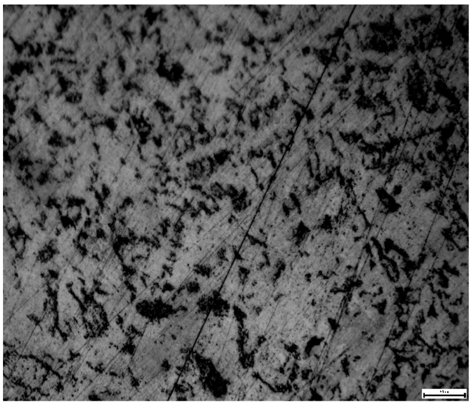
X3 external bottom plate underneath corrosion

Fig. 11 Microstructure of the corroded sample.

III. DISCUSSION

The study shows that the intensive corrosion attack is associated with bottom plate of the tank. The internal side of the tank bottom is in direct contact with stored fuel, and may expose to water, salts, and organic deposits. The external side of the tank bottom is in direct contact with soil that may contain salts or moisture.

The presence of water in oil tanks is inventible, so water accumulates on the bottom of the tank, further initiates and propagates corrosion failure. Deposits on metal surface such as mill scale or biofilms may develop different oxygen concentration cells, because of the difference in oxygen concentration between the area under the film and the surrounding electrolyte. Subsequently creates a localized area of lower oxygen concentration and may result substantial metal loss. Microorganisms either SRB or IB developed on the metal surfaces can form biofilms that create nonuniform surface conditions. Subsequently localized attack might start at some points on the surface and severely affects the kinetics of cathodic and anodic reactions in an electrochemical process, leading to localized corrosion in the form of pitting.

Damage in the rubber ring, as well as ring asphaltic as a result of erosion occurred by rain, humidity, temperature, resulting in water leaks and moisture going under an annular bottom plate along the entire water proof asphaltic layer. Then the reaction starts and progresses allowing a type of bacteria to attack the steel bottom panel causing under such localized corrosion spread in different locations and this leads to a fuel oil spill. The thick accumulated fuel oil (sludge) layer on the tank bottom may assist the internal corrosion to occur. This may impede (shield) the protective current distribution and promote the bacteria environment (serve as a food supply) in addition to the present of asphalt layer as well under the tank bottom plates. Cathode protection system works well but as a result of occurrence of leaking which change the corrosion environment characteristics, so changes in the bottom of the tank to soil parameters required such as voltage, resistivity, and other interactions. It is also the absence of coating on bottom plate speeds up the corrosion process.

The gaps are formed between the plate and the ground beneath the tank bottom plates due to the heaving behavior where some location is no longer setting on the soil ground while others do. This may occur as a result of distortions of the bottom plates because of welding. This causes discontinuity of the electrical connection between the electrolyte and the entire surface of the bottom plate, that is necessary requirements for cathodic protection. Consequently, causing a loss of corrosion protection.

IV. CONCLUSION

This work focused on the integrity of the above ground storage tanks of heavy fuel. A severe corrosion failure was observed on the tank bottom plate at several locations. Corroded samples were examined for microstructure, and thickness loss. Analysis on the cause of corrosion was interpreted to identify the corrosion mechanism occurred. The absence of external annular ring sealing allow the moisture to enter below the bottom and touches lower part of the shell particularly causing loclized corssion. The presence of water in oil tanks is another cause for corrosion initiation and progress, in the absence of bottom plate lining. High corrosion rates determined requires the inspection has to be rescheduled.

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