Comparison of Corrosion Attack on Tank Bottoms With and Without Cathodic Protection

I.Y. Barnawi, *Saudi Aramco, Ras Tanura, Saudi Arabia*

This study was conducted to compare the corrosion attack on the underside of storage tank bottoms protected with cathodic protection (CP) and tank bottoms without CP. The study is based on historical inspection records, CP potential measurements, and results of magnetic flux leakage testing.

The Terminal Department of Saudi Aramco is the custodian of more than 150 storage tanks ranging in diameter from <50 ft (15 m) to >375 ft (114 m). The tanks were built at three terminals: Ju'aymah Terminal, North Terminal, and South Terminal. Nine tanks—three from Ju'aymah Terminal, two from North Terminal, and four from South Terminal—were randomly selected for comparison of underside corrosion.

The selected tanks were divided into three categories (Table 1):

1) Tanks protected by impressed current cathodic protection (ICCP) shallow anode beds
2) Tanks with double bottoms protected by galvanic ribbon anodes or ICCP with mixed metal oxide (MMO) anodes
3) Tanks without CP

All tanks are built per API 650,[1] Section 2. The inboard and sketch plates are 10-mm thick carbon steel (CS) per ASTM A283[2] and the plates of the double bottom tanks are 6.3-mm thick.

Discussion of Failures

Tanks with CP (Shallow Anode Beds)

Five tanks were selected for corrosion comparison (Table 1): Tanks J-1, J-2, and J-3 from Ju'aymah Terminal, all 375 ft in diameter; and Tanks N-1 and N-2 from North Terminal, which are 354 ft (108 m) in diameter.

Ju'aymah Terminal

The selected tanks at this terminal were built in 1974 per API 650. The bottom plates were laid on 4-in (102-mm) thick pads of oily sand. Each tank is protected by 12 silicon iron anodes distributed equally around the tank at a depth of 6 to 8 ft (1.8 to 2.4 m).

The average CP current produced for each tank is 60 A. The CP potential is

TABLE 1

Comparison of corrosion attack on tank bottoms protected with and without CP

Tank No.	Year Built	Dia. (ft)	Age of Bottom Plates (y)	Visual Inspection/ MFL Results	No. of Plates 40-59% Metal Loss	No. of Plates 60-100% Metal Loss	Annular	Sketch	Inboard	% of Salts Contained in Oily Sand	Calculated Corrosion Pitting Rate (mpy)	CP	Avg. CP Potential (mV)
Ju'aymah Terminal Tanks													
J-1	1974	375	36	1/1/1989	22	53	0	3	50	0.49	26.3	Yes	–1,223
				4/1/1999	35	101	0	9	92				
J-2	1974	375	36	2/1/1997	62	23	0	1	22	0.16	17.1	Yes	–1,090
				7/1/2008	80	84	15	40	29				
J-3	1978	375	34	8/1/1986	36	15	0	12	3	0.21	32.8	Yes	–1,026
				6/1/2002	52	79	0	21	58				
North Terminal Tanks													
N-1	1972	354	38	3/7/1984	15	14	0	12	2	0.6	32.8	Yes	–1,021
				11/1/2009	55	70	1	21	48			Yes	
N-2	1973	354	37	6/1/1985	23	5	0	3	2	0.2	36	Yes	–1,321
				8/1/2006	28	31	0	10	21			Yes	
South Terminal Tanks													
S-1	1956	164	10[A]	6/1/1996	45	85	All	All	All	0.44	13.2	No	NA
				10/1/2008	7	0	0	0	0	0.1		Yes	–1,225
S-2	1938	164	10[A]	6/20/1997	32	98	All	All	All		25.2	No	NA
				12/1/2009	6	5	0	2	3	0.1		Yes	–1,033
S-3	1974	374	36	6/1/1997	6	0	0	6	0	0.2	10.3	No	NA
				1/1/2010	13	0	0	0	0			No	
S-4	1974	374	36	3/1/2000	53	88	0	137	70	0.45	28	No	NA
				10/15/2004	27	70	0	22	58			No	

[A]Replaced after 30 years of service.

measured at each quadrant of the tank through four soil access holes located outside the ringwall and four permanent zinc reference electrodes installed under the tank bottoms. The average CP potential measured during the annual surveys for the selected tanks has always been above the minimum acceptable criteria of the company's engineering standard (–1,000 mV with CP "on").

Tank J-1

During the first test and inspection (T&I) in 1989, visual inspection revealed 23 holes on the bottom plates that were caused by underside corrosion and 53 plates—50 inboard and three sketch—with a metal loss of 60 to 90%. Table 1 shows the test results. Soil tests indicated that the salts content in the oily sand was 0.49% while the maximum recommended amount is 0.1%.

In addition, consolidation gaps of 1 to 3 in (25 to 76 mm) between the bottom plates and oily sand were noticed. The gaps were filled by grout slurry made of 67% sand, 20% cement, 1% bentonite, and 12% water.

In January 1998, a leak was reported. Investigations revealed that the leak was caused by underside corrosion. After the tank was cleaned for a T&I, magnetic flux leakage (MFL) testing and visual inspection discovered 52 holes, and 101 plates had a metal loss of 60 to 100%, an increase of 130% in the number of holes and 90% in the number of corroded plates since the 1989 T&I. The corrosion was mostly concentrated in one half of the tank (Figure 1).

Tank J-3

During the first T&I in 1986, after 10 years of service, visual inspection revealed 30 holes in 15 bottom plates due to underside corrosion. In addition, 12 sketch plates and 37 inboard plates had a metal loss between 60 to 90%. The oily sand salt content was 0.21% while the allowable amount was 0.1%. Gaps of 1 to 2 in (51 mm) between the oily sand and bottom plates were also observed.

In 1996, T&I was deferred. In June 2002, during the second T&I, a MFL survey and visual inspection discovered 353 holes and 79 plates with metal loss of 60 to 80%, an increase of >1,100% in the number of holes and 160% in the number of corroded plates since the previous T&I.

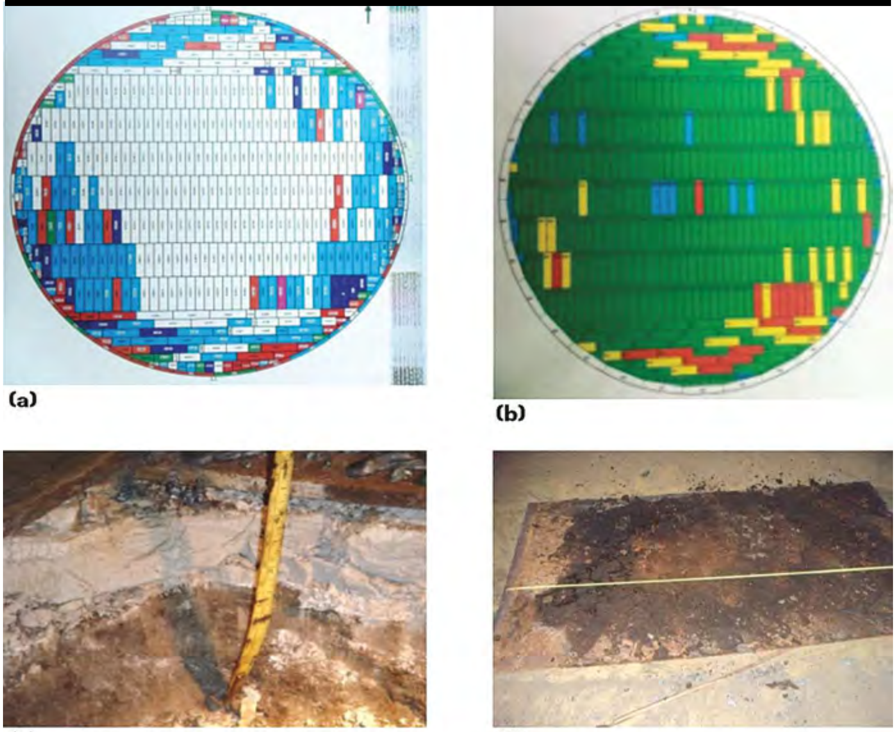
Tank J-2

Compared to the other two tanks J-1 and J-3, this tank had minor underside corrosion during the first 10 years of service. In 1986, during the first T&I, the minimum reported ultrasonic test (UT) reading was 0.348 in (8.8 mm), indicating a metal loss of 0.067 in (1.7 mm) (18%) from the original 0.375-in (9.5-mm) plate thickness.

In 1997, the second T&I visual inspection and MFL testing revealed 125 additional holes in 23 plates—22 inboard and one sketch plate—and a metal loss of 60 to 80%. Gaps of 1 to 3 in between the oily sand pad and the bottom plates were noticed.

The third T&I of this tank was conducted in 2008. Visual inspection and MFL testing confirmed 139 holes, and 84 plates (15 annular, 40 sketch, and 29 inboard) had a metal loss of 60 to 80%, an increase of 11% in holes and 265% of corroded plates since the last T&I.

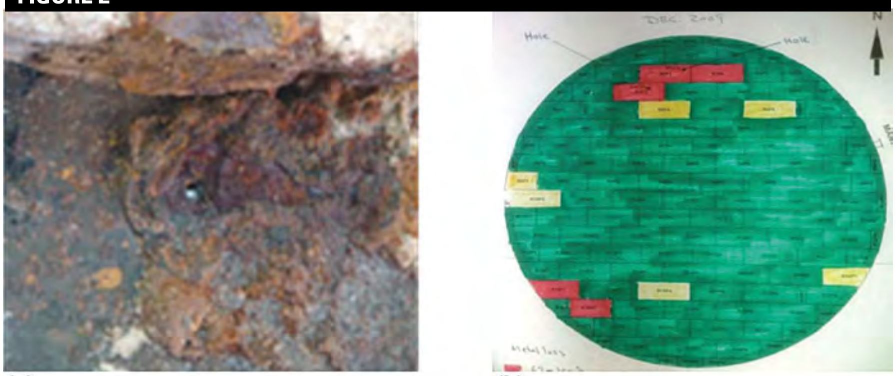
FIGURE 1



(a) (b) (c) (d)

Bottom inspection of Tank J-1 at Ju'aymah Terminal. (a) 2008 MFL test result, (b) 1997 MFL test result, (c) injected grout, and (d) corrosion scale under bottom plates.

FIGURE 2



(a) (b)

Bottom inspection Tank S-2 at South Terminal. (a) Penetration of bottom plate and (b) 2009 MFL test result.

North Terminal Tanks

The selected tanks at this terminal were built in 1972 per API 650. Similar to the Ju'aymah Terminal tanks, the bottom plates of these tanks were also built on oily sand pads. Each tank is protected by 10 silicon iron anodes distributed equally around the tank at a depth of 6 to 8 ft.

The total protective current for each tank is ~80 A. The CP potential is measured at eight soil access holes distributed equally around the periphery of the tank.

Tank N-1

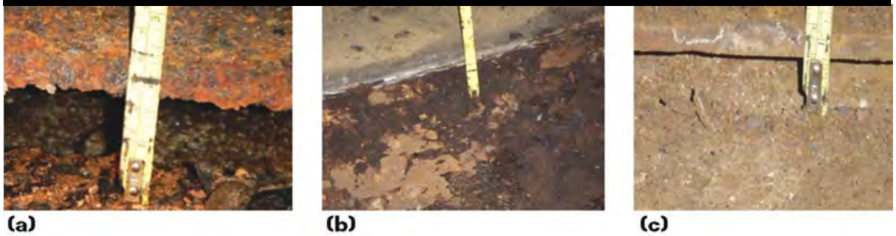
During the first T&I (1985), visual inspection and MFL testing discovered 23 scattered holes in 14 plates (12 sketch and two inboard). Severe underside corrosion with more than 75% metal loss was reported on 155 plates (20 inboard and 135 sketch). In 1997, during the second T&I, a metal loss of 10 to 40% was noticed on the inboard and sketch plates. In the third T&I in 2009, the MFL testing report indicated a metal loss of 60 to 80% on 72 plates (one annular, 42 sketch, and 29 inboard) due to underside corrosion.

Tank N-2

Ten holes in two inboard plates and metal loss of 60 to 80% were reported on five plates (three sketch and two inboard) during the first T&I in 1986. Gaps of 1 to 2 in between the oily sand pad and the tank bottom were noticed.

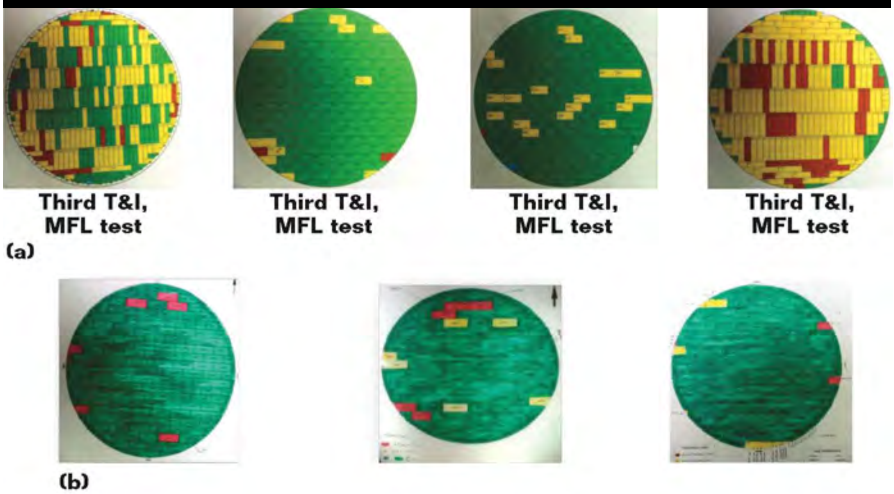
In 1997, during the second T&I, 15 plates (eight sketch and seven inboard) had metal loss of 60 to 80% due to underside corrosion. The corroded plates were all replaced. In the third T&I (2006), visual inspection and MFL testing

FIGURE 3



Underside corrosion of tank bottoms. (a) First T&I, MFL test of MMO anodes, (b) first T&I, MFL test of magnesium ribbon anodes, and (c) first T&I, MFL test of zinc ribbon anodes.

FIGURE 4



MFL test reports of various tank bottoms with and without CP. (a) Tank bottoms without CP and (b) double-bottom tanks protected by galvanic ribbon anodes/ICCP MMO anodes.

discovered seven holes on two inboard plates, and 40 plates with metal loss of more than 60%.

South Terminal

Double Bottom Tanks

Due to underside corrosion on the bottom plates of Tanks S-1 and S-2—both 164 ft (50 m) in diameter—the entire bottoms of both tanks were replaced in 1997 and 1998, respectively, after 30 years of service. The old bottoms were replaced with a 6.3-mm thick ASTM A283 CS.

To protect the new bottoms from underside corrosion, the following steps were taken:

> The old bottom was covered by polyethylene sheets (15-mils [0.38-mm] thick).
>
> A 4-in layer of sweet sand (low salt content ~0.1%) was laid on the polyethylene sheet.
>
> CP was also introduced. Tank S-2 was protected using galvanic magnesium ribbon anodes, while tank S-1 was protected by an ICCP system using MMO anodes.
>
> Four zinc reference electrodes were installed to measure the CP potential at different locations.
>
> The entire underside of the bottom plates was coated with coal tar epoxy.

After the first 10 years of service, the tanks were opened for T&I. Visual inspection and MFL testing were performed to check the integrity of the bottom plates. The report indicated that the bottom of Tank S-2, which was protected by zinc ribbon anodes, had developed two holes on two different plates due to underside corrosion (Figure 2 and Table 1).

On the other hand, the bottom of Tank S-1, which was protected by ICCP with MMO anodes, was generally in good condition, except for a few plates where metal loss of 60% was reported at various locations. Although the salt content in the sand for both tanks was within the standard requirement, the calculated corrosion rate was very high, 13.2 mpy for Tank S-1 and 25.2 mpy for Tank S-2.

Tanks Without CP

Two tanks (Tanks S-3 and S-4) were selected to compare underside corrosion of their bottom plates with tanks that are protected with CP. Both of the selected tanks, built in 1974, are 374 ft (114 m) in diameter on oily sand pads.

During the first T&I cycle on Tank S-4, after 10 years of service, three holes were reported due to underside corrosion in addition to >50% metal loss at various locations. In March 2000, during the second T&I, MFL testing and visual inspection discovered 207 holes on 88 plates. The calculated corrosion rate was 28 mpy.

In 2004, the tank was reopened for maintenance. Visual inspection and MFL testing reports indicated 95 holes on 70 plates. All plates with more than 60% metal loss were replaced.

For Tank S-3, no major metal loss was reported during the first T&I and UT scanning revealed a metal loss of <20%. During the second T&I in 1997, MFL testing and visual inspection showed metal loss of 40 to 60% on six plates. In January 2010, during another T&I, MFL testing and visual inspection reports revealed 13 plates had metal loss of 40 to 60% due to underside corrosion.

Conclusions

There appears to be consensus that the result of underside corrosion on tank bottoms is caused by the following:

- All types of tanks (tanks protected with ICCP and galvanic ribbon anodes, as well as tanks without CP) have suffered from underside corrosion.
- Gaps of 1 to 3 in between sand pads and tank bottoms were noticed in all tanks (Figure 3).
- Some tank bottoms without CP are in better condition than tanks protected by CP (Figure 4).
- The oily sand at some tanks is very solid and dry—creating a high resistance path for the CP current to flow to the tank bottom.
- Not all types of CP systems are fully effective in protecting the tank bottoms, due to the high resistance of the oily sand and gaps between the oily sand and tank bottoms.
- High content of salts in the sand pads from previous leaks, in addition to the corrosive water that accumulates under the tank bottoms, will cause more corrosion in the future.
- The design life of the magnesium ribbon anodes in double bottom tanks is <10 years, which is much less than the calculated design life of 40 years.
- The measured CP potential during the annual CP survey is not representative of the actual condition of the bottom plates.
- Grouting the tank bottoms could cause more corrosion, since a lot of moisture is present with the grout.

Recommendations

- Discontinue the application of CP on tank bottoms that are built on oily sand pads.
- Introduce new applications to protect tank bottoms, such as vapor phase inhibitors.
- Reevaluate the design of galvanic ribbon anodes for tank bottoms.

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I.Y. BARNAWI is the supervisor of the Terminal Dept./Terminal Inspection Unit at Saudi Aramco, Box 4815, Ras Tanura, 31311, Saudi Arabia, e-mail: birnawiy@aramco.com. He has worked in the areas of CP and coatings for 21 years, including nondestructive testing for hydrocarbon storage tanks, offshore structures, and subsea pipelines. He is a member of the Saudi Aramco Engineering Standard Committee of Cathodic Protection Standards and is a NACE International-certified CP Specialist and Senior Corrosion Technologist. *MP*