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# Integrity Challenges & Control - Tank Bottom Corrosion Shakeel Isak Girkar

ADCO, Abu Dhabi, United Arab Emirates sgirkar@adco.ae

# Ajiv Mohan Nair, Renjith Vijayan Mangattu

ADCO, Abu Dhabi, United Arab Emirates

# ABSTRACT

One of the leading Middle East Oil Operator has total 116 oil storage tanks. All crude oil tank and facility storage tank bottom plates are externally protected against soil-side corrosion with Impressed Current Cathodic Protection (ICCP) System.

Corrosion and subsequent failure, particularly on storage tanks bottom plates, is one of the main factors upsetting any upstream/downstream production facilities. Maintaining adequate level of CP system is always a challenge for corrosion engineers due to complex corrosion phenomena. Failure of storage tanks during production stage due to corrosion can be catastrophic with following consequences:

- Loss of life(fatality)
- Safety and Environment(Fire, Toxic gases and Oil Spill)
- Resource and downtime cost impact
- Damage to asset/company reputation.

As per current industrial practice, above ground storage tanks' bottom plates are designed to be protected externally with ICCP system. However, the CP effectiveness often becomes challenging due to presence of air gap occurring between bottom plate and sand cushion. Such air gaps eventually lead to ineffectiveness of CP system due to restricted current flow. The situation aggravates when moisture ingress occurs through annular area of the concrete foundation and settles underneath the bottom plate surfaces.

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This paper focuses on case study of crude oil tank bottom plate failure due to corrosion and discusses its causes, design and installation errors, analysis of CP effectiveness, inspection strategy, interpretation of damage mechanism and recommendations.

Keywords: Corrosion, Damage Mechanism, Coating, Cathodic Protection, Storage Tanks, External Bottom Plates, Air Gap, Soil Compaction.

### INTRODUCTION

One of the leading Field's CDS facilities mainly consist of 3 nos. of Crude oil storage tanks and 5nos.of fresh/disposal water storage tanks, for which Cathodic Protection system is applied both internal and external ( soil side bottom plate) surfaces. External ICCP system with MMO grid anodes were used to protect storage tank bottom plates from soil side corrosion. The installed CP system is being monitored for its effectiveness as per International and company standards. Soil-side corrosion of the bottom plates is a major challenge since the tanks are constructed on concrete ring walls along with sand cushion. Application of CP underneath the bottom plates requires utmost design considerations and closed QC supervision during installation stage itself. Subsequent operation and maintenance of CP system becomes often challenging due to development of airgaps between tank bottom plates and sand cushion.

Crude oil storage tank A was constructed in 2006 and commissioned in 2007 along with grid anode ICCP system. Construction detail of the subject tank is as below;

Equipment Description : TANK A	Year of Commissioning : 2007				
Design Code : API STD 650	Material Specification : A 516 Gr. 60 N				
Design Thickness : 10 mm (Bottom Plate)	Corrosion Allowance (Shell/bottom/roof::3.0/3.0/1.0mm)				
Design Pressure (barg):15.2 m bar g	Design Liquid Level : 9.5 meter				
Nominal Diameter : 30.5 meter	Nominal Height : 12.2 meter				
Max. Operating Temp : 85'c	Specific Gravity: 0.84				

#### **Table 1: Construction Information Tank A**

A RBI analysis conducted in 2014 and the tank was subsequently planned for Off-stream inspection in 2015.

Magnetic Flux Leakage (MFL) and subsequent confirmation with Ultrasonic Test (UT) scanning of bottom and annular plate revealed an average metal loss from 60% to 70%. Soil side corrosion was the predominant factor resulting in heavy metal loss of the bottom plate. Through thickness holes were also observed at 8 locations (Figure 1&2)

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Figure (1)

It was noted that the external corrosion pits were developed on or near to the annular plate.



Figure (2)

## **INVESTIGATIONS:**

A strategy conducted by company's Corrosion team proposed an investigation method to study damage mechanism and alleviate causes of corrosion.

The team concluded that installation of CP with MMO Grid anode system during construction time might have missed QC measures like soil quality as per NACE SP0193-2016resulting in providing inadequate protection level of Cathodic Protection system, which may have resulted in deep pitting on external soil-side bottom plate. The team recommended providing sweet sand compaction in order to fill the air gap which is developed underneath the tank bottom plate with stringent QC measures. A suitable internal lining with FRP is also recommended to provide on bottom plate and shell up to 2.5 mtr (expected water level).

#### DISCUSSIONS

- Original bottom & annular plate thickness is 10mm and the bottom plate is protected from inside with GRV lining along with SACP (Aluminum anode) system.
- The ICCP for bottom plate (soil side) was working satisfactorily in line with International criteria (100mv polarization shift criteria).
- Tank bottom is equipped with proper leak detection & release prevention barrier. Sludge and deposits at a height of approximately 800 mm was found inside the tank. Sludge analysis showed that majority of the material is from hydrocarbon with chemicals. These chemical are expected to be bactericide mixed with corrosion inhibitor.
- Scale analysis from the cut plates showed that the majority was iron oxide mixed with sand.
- MFL & Subsequent confirmation with UT scanning of bottom and annular plate revealed metal loss between 60% to 70% (ref fig.1&2)
- Corrosion was predominantly in the annular plates emanating from soil side; however the bottom plate was also affected. Critical zone (radial area within 3" from the bottom to shell joint) found with no significant corrosion. Sump plates and plates in the outlet area found with no significant corrosion.
- Soil side deposits were found with high level of chlorides with iron oxide which revealed that the sand under bottom plate was contaminated with chlorides. 8 Nos of through thickness holes were observed 4 out of which depicted water side corrosion morphology due to seepage of contaminated water through micro cracks in the coating.
- Bottom plate sealing (external) was found to be detached and deteriorated at some places (5 % of the total circumference)

## **REVIEW OF EXTERNAL ICCP SYSTEM AND ITS EFFECTIVENESS**

Since the corrosion was found to be unexpectedly significant despite of having adequate CP system protection levels, the present grid anode CP system necessarily called for an integrity assessment/audit.

#### BACK GROUND

The CP system was designed and installed along with tank erection stage; however, it was commissioned after two years.

MMO grid anode system was considered as ICCP anode bed configuration due to below advantages;

- i. Easy to install for new tanks at construction stage.
- ii. Provide highest degree of design certainty.
- iii. Can ensure effective uniform current distribution to entire tank bottom and effective protection can be achieved.

Sequence and cross sectional view of the installed CP system and tank bottom arrangements as illustrated in figure 3 & 4



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Figure (4)

## **REVIEW/ASSESSMENT OF PAST MONITORING DATA**

- The CP system observed to be continuous in operation delivering an output current of around 18Amps as per the initial calculated design current.
- Past CP monitoring reports indicate that the tank bottom plate is adequately protected right from the commissioning stage.
- Substantial increase in IR drop noticed with the time, which indicates eventual increase in circuit resistance.
- This may be due to development of irregular 'air gaps' underneath the tank bottom.
- By analyzing the nature of potential profile taken along the perforated monitoring duct, it is concluded that the air gaps are concentrated near to the annular plate area. This phenomenon might have occurred due to the deployment of crushed stone / gravel underneath the annular plates as per tank design where the covered sand might have lost contact with the metal with passage of time.

#### **CORROSION DAMAGE MECHANISM ANALYSIS**

3 Nos. Metal samples were cut from tank bottom along with surrounding soil/corrosion products and sent for further lab analysis to conduct below tests;

- i. Visual examination and photograph.
- ii. Chemical analysis of the plate material.
- iii. Macro examination.
- iv. Microstructure examination.
- v. SEM EDS analysis of the corrosion products / scales.
- vi. Chemical Analysis of the scale samples.
- vii. XRD analysis of the scale samples.

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## RESULTS

Within light of the test results and analysis, the below points are drawn;

- i. Chemical composition of the tested plate material found to be Carbon Steel confirming to ASTM 516 Gr. 65.
- ii. Metallurgical evaluation of the general microstructure and affected areas of the three test samples revealed no inherent metallurgical abnormalities which could have contributed to the failure.
- iii. No evident corrosion damage was found on the water side of the three samples.
- iv. Failure of the three plate samples can be mainly attributed to severe pitting corrosion. All the corrosion pits / holes initiated from the soil side surface, which is likely due to accumulated moisture on the soil side of tank bottom plates.(Figure 5 and 5a)
- v. The observed pits / holes are filled with black and brown color corrosion products, SEM EDS analysis showed that these are mainly Iron Oxides with high amount of Chlorides. (Figure 6)
- vi. XRD analysis on soil Lump covering pit confirms the tubercles consist of mainly iron oxides and hydroxides.(Figure 7)



Figure (5)

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Figure (5a)

#### **METALLURGICAL ANALYSIS**





Spectrum	С	0	Na	Si	CI	K	Mn	Fe	Total
Spectrum 1	7.98	42.31	0.79	0.33	0.25	0.20	0.58	47.57	100.00
Spectrum 2	3.10	42.30			4.11		0.85	49.65	100.00
Spectrum 3	3.74	37.57			4.51		0.51	53.67	100.00

All results in weight%

Figure (6)

SEM EDS analysis shown that the corrosion products are mainly Iron Oxides with high amount of Chlorides.

#### - A12-Pit Soil Lump Covering



#### Figure (7)

X-ray diffraction analysis of the sample plates' soil side indicated the tubercles consisting mainly of iron oxides and hydroxides.

#### RECOMMENDATIONS

#### **IMMEDIATE ACTION PLAN**

- In view of extensive underside corrosion attack of tank bottom annular plates (associated with high loss of wall thickness) it was recommended to replace the affected annular plates completely with new plates, perform the welding of annular plate with shell and carry out field hydro test.
- Apply GRE lining system (3.00mm OFT) at tank floor and shell up to 2.5 mtrs. height (water level) meanwhile eliminates the installation of sacrificial anodes.
- Repair and rectify the sealing arrangement as per approved foundation drawing to achieve 100% sealing and avoid moisture ingress.
- Replace the crushed stone with clean sand in the marked zone with a min. depth of 50mm underside the annular plate, which will avoid air gaps and ensure better Cathodic Protection.

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- The wall thickness of bottom plate patches to have the same wall thickness of the original bottom plate (10mm) and should have rounded corners.
- Conduct performance review for the existing CP system of tank floor external surface.

## CONCLUSIONS

- No evident corrosion was found on the water side of the three cut samples.
- Failure of the three plates can be mainly due to severe pitting external corrosion. All the corrosion pits/holes initiated from soil side surface, which is likely due to ingress of moisture and oxygen through gaps between annular plates and tank foundation, in the presence of Chloride ions. SEM EDS analysis and X-ray diffraction analysis on the soil side of the sample plates further confirmed the presence of tubercles of mainly iron oxides& hydroxides with chlorides. Hence 100 % sealing of the referred gap is essential.
- For effective corrosion prevention and tank bottom CP,Stringent QC measures like clean chloride free sand bedding as per NACE SP0193-2016combined with ICCP system, without any subsequent air gap developments in future by ensuring proper soil compaction are required. The use of oily sand crushed stone, asphalt or any other materials directly under the tank bottom shall be avoided, to have effective ICCP system performance.
- Design and implementation of linear anodes concentric ring anode system along with dedicated TR unit which has advantages over existing grid anode system is recommended during next tank shutdown. Such anodes are typically backfilled within a prepackaged tube filled with a high quality carbon backfill. This enhanced back fill protects the anode from any mechanical damages during its erection, improves performance and reduce system resistance. The main advantage of such back fill is it can reduce depolarization caused by oxygen generation.

Typical proposed anode configuration is shown below as Figure 8.

#### CONCENTRIC RING ANODE SYSTEM



\*Number of Rings Varies with Tank Diameter





Figure (8)

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## ABBREVIATIONS

- CP Cathodic protection
- SACP Sacrificial Anode Cathodic Protection
- ICCP Impressed Current Cathodic Protection
- DC Direct Current
- pH Potential of Hydrogen
- RCC Reinforced Cement Concrete
- U/G Under Ground
- CBF Coating Breakdown Factor
- UV Ultra Violet
- CIMS Corrosion & Inspection Management System
- SEM Scanning Electron Microscope
- EDS Energy Dispersive X-ray Spectroscope.