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Successful Implementation of a Corrosion Management Strategy by Online Injection of Vapor Phase Corrosion Inhibitors to Extend Storage Tank Floor Life

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ABSTRACT

The API(1) 650 Oil storage tanks in the refinery have experienced accelerated corrosion from the soil side at the rate of 1-2mm/year primarily due to inefficiency of the impressed current cathodic protection system and under-deposit corrosion caused by the presence of corrosive bacteria in the soil (detailed failure analysis presented in NACE(2) Paper # C2017-9025). This has caused failure of several tank bottom plates within 8 years of commissioning resulting in loss of primary containment. With no other means of corrosion control from the soil side, the priority was to apply a short term stratagem by which the corrosion rate is substantially slowed and enable the refinery to distribute these tank turnarounds across as many years as possible. If this is not achieved, then a large number of tanks might be expected to perforate in any given year overwhelming refinery maintenance and disrupting operations.

The short term strategy adopted with best likelihood of success and minimal disruption to maintenance and operations was to drill under the tanks and inject vapor phase corrosion inhibitors. The primary objective is to increase the reliability by extending the floor life and meeting the agreed tank out of service schedule

Considering the same probability of failure for all 48 nos. tank, a consequence based risk ranking was carried out to roll out the chemical injection plan in a phased manner. Based on the risk ranking, 21nos. tanks were identified for the first phase, which was implemented in 2016, followed by other tanks in subsequent years. The efficiency of the inhibitors was monitored by the use of a number Electric Resistance (ER) probes that have been installed at various locations underneath the tank bottom. A detailed cost benefit analysis was also conducted to realize the savings between the chemical injection and having to deal with multiple tank rebottoming.

This article describes the online injection method, the inhibitor efficiency by measuring corrosion rates pre & post chemical injection along with the benefits achieved by implementing this online corrosion management strategy to extend the tank floor life.

Key Words: Above ground Storage Tanks, Soil Side Corrosion, VPCI, Electrical resistance probes,

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(2) NACE International, Houston, Texas, USA

INTRODUCTION

The soil side corrosion of above-ground storage tanks (AST's) is a chronic problem in the oil and gas industry not only in the middle east but also in the world at large [1]. Corrosion of the underside of the tank bottom plates leads to metal loss and perforations resulting in loss of primary containment. The results of such failures are dramatic on multiple fronts: loss of product, costly repairs, and environmental impact and safety concerns in the case of flammable fluids.

Traditionally, Cathodic Protection (CP) has been used for corrosion management of tank bottoms. However, experience has shown that CP fails to provide adequate protection in some types of AST construction.

Suhar Refinery is a part of Oman Oil Refineries and Petroleum Industries Company (ORPIC) [(3)], Oman. It was commissioned in 2006 and has 48 ASTs (Above-ground Storage Tanks) for various refinery products. The refinery tanks have experienced severe corrosion at a very high rate from the underside (soil) side of the bottom plates and resulted in failures of more than 6 tanks within 10 years of commissioning (2006), with the first failure in 2013. Tanks floors are expected to provide service life of over 30 years.

From Root Cause Analysis Study (RCA), it was concluded that the tanks were corroding at an unacceptably high rate and the corrosion was specifically related to the inadequate strategy of CP design which completely failed in its objective of corrosion control combined with a corrosive soil.

The priority was to apply a short term stratagem by which the corrosion rate is substantially slowed and enable refinery to distribute these tank turnarounds across as many years as possible. Otherwise, a large number of tanks might be expected to perforate in any given year overwhelming maintenance and disrupting operations.

The immediate strategy with best likelihood of success and minimal disruption to maintenance and operations was to drill under the tanks and inject Vapor Phase Corrosion Inhibitors (VPCI). These inhibitors have been increasingly used in this particular application for the last 15 years with proven results. The inhibitors can help control the corrosion and prevent any further corrosion by forming a layer on the metal surface and restricting the corrosion reactions.

This paper demonstrates the concept of using an amine carboxylate based VPCI slurry, as an online soil-side corrosion control method for in-service refinery storage tanks coupled with ER corrosion probes monitoring and exemplify the difference in cost by using VPCI and other maintenance options such as patch plate repair or jacking up and rebottoming of the AST tanks.

Fundamental of VPCI Technology in Above-Ground Storage Tanks (ASTs)

Amine carboxylate-based VPCIs are used beneath aboveground storage tanks. They are effective for prevention of metal corrosion when a VPCI product is released within the interstitial space between the bottom plate and sand pad. The mechanism for corrosion control is the formation of a monomolecular layer throughout the soil-side surface of the tank floor. VPCI molecules adsorb on the steel surface to suppress both metal dissolution and the reduction reaction (both the anodic and cathodic processes). This adsorption is accomplished without the need for direct contact of the VPCI chemical on the metal surface.

[(3)] Oman Oil Refineries and Petroleum Industries Company, Sultanate of Oman.

The effectiveness of any corrosion inhibitor can be evaluated using electric resistance (ER) probes and the same is valid for VPCI used for soil-side corrosion in AST's. Since the sensing element of the ER probe is usually made of an alloy with the same grade as the tank bottom plate, it is believed that the data obtained from these probes are more representative of AST bottom plate corrosion[4].

The probe sensing tip is mild steel and will corrode at a rate similar to the tank floor in that area. Readings of metal loss in mils are obtained from the ER probes with a special meter, which is incorporated into a formula that produces a rate of corrosion in mils per year (mpy).

VPCI APPLICATION PROJECT

The refinery experienced its first tank failure in July 2013 when Sour water tank experienced bottom plate perforations due to soil side corrosion after 7 years in service. Magnetic flux leakage (MFL) survey was carried out for the floor and it revealed more than 40% reduction in majority of the plates. The most severe corrosion (80-100%) with perforations was observed only in the peripheral sketch plates adjacent to the annular plates, Figure 1. This gives a corrosion rate of almost 1mm/year in the corner plates and 0.4mm/year at the other bottom plates.

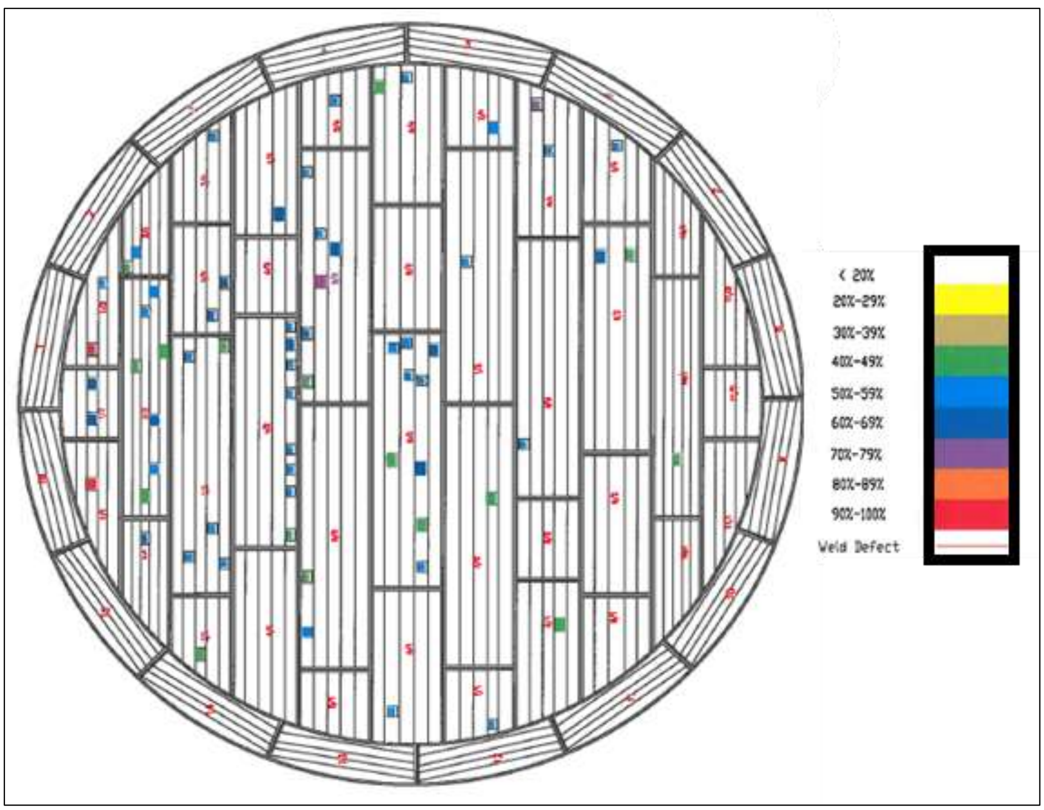

Figure 1: MFL floor scan results for Sour Water Tank.

The tank was patch plate repaired and VPCI was injected for soil side protection along with ER probes which installed to monitor the efficiency of the chemical and corrosion rates. The injection of VPCI was from inside tank during off-stream period. There were seven injection ports in different locations of the tank floor to fog VPCI powder, and four points in ring wall were cored to introduce sleeves for installing of ER probes to monitor the effectiveness of VPCI slurry. Figure 2.

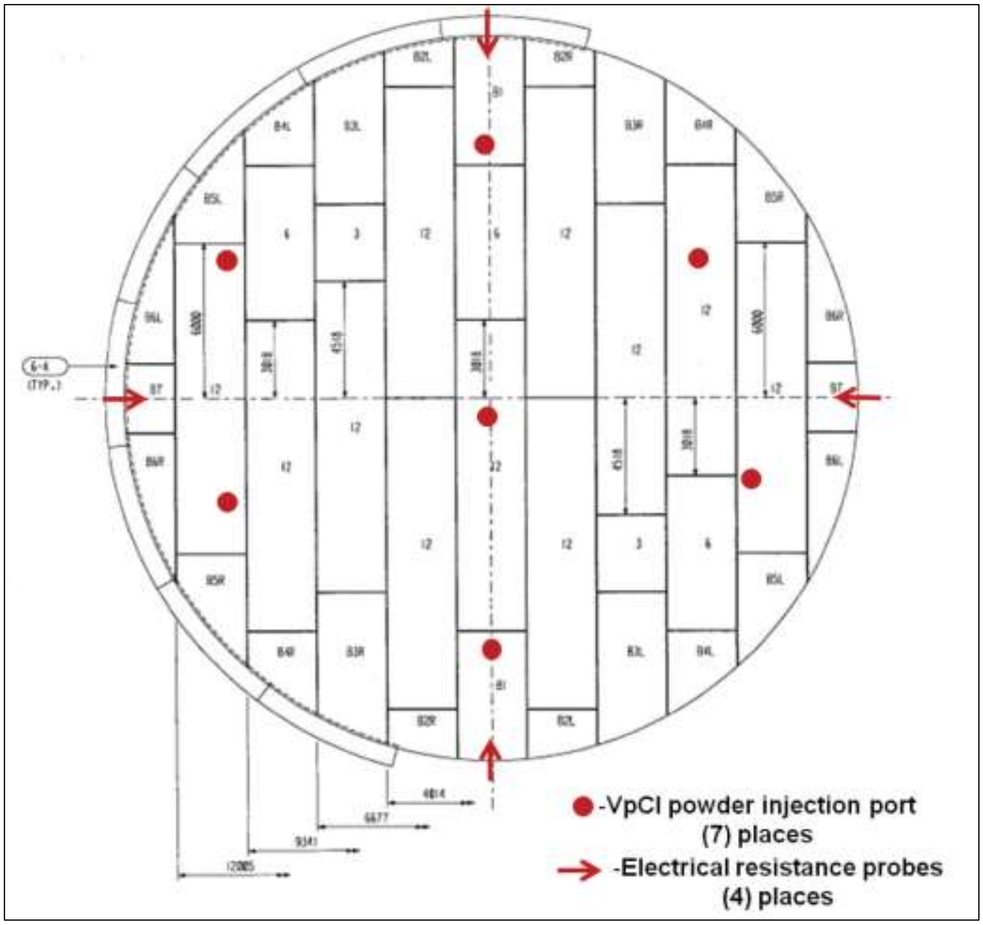

Figure 2: Plan view with ER probes and VPCI injection port locations

Subsequently, multiple tank failures were observed with another 5 no tanks experiencing severe bottom plate underside corrosion. Similar MFL results as the sour water tanks were revealed. The patch plate repair method was adopted for 3 tanks, whereas for 2 tanks rebottoming was carried out by jacking-up the tank. The re-bottomed tanks were replaced with bitumen foundation as the corrosion protection barrier. Consequent to the failures, a detailed CP survey was carried out for the storage tanks in 2016. The previous CP survey was done in 2008. Both surveys show very low instant OFF potentials for all the tanks with an average of -450 mv CSE which highlight that the CP system has failed in its design purpose and inadequate protection to ASTs bottom plate.[2]

As it is not a practical to inspect all the tanks, an out of service schedule (OOS) was agreed by all stakeholders of the plant with the intention of implementing an online corrosion protection strategy to extend the service life of the tanks and meet the OOS schedule. The refinery evaluated all possible options with its feasibility based on cost/time and success factor. As the ICCP system is placed between the tank bottom and a HDPE liner, there is no possibility of providing any additional external anodes due to shielding effect of the plastic sheet. Hence, as there is no direct access to the CP system, any rectification would mean to jack-up the tank and have access to the soil. Secondly it would require complete re-designing of the CP system with hardware changes and also new T/R units. In spite of all this, still bottom plate replacement would be required and there is uncertainty on achieving protection potentials.

Therefore, the refinery identified other possible short term options that would extend the tank life to meet the OOS schedule. The immediate solution adopted was to inject corrosion inhibitors without any disruption to the operations and seal the chime area of the tanks to avoid any further air or moisture ingress.

Instantly, number of tanks were identified based on a consequence based risk ranking for the implementation of online injection of VPCI and installation of ER probes to evaluate the effectiveness of this technology. The main objective of the project was to extend the service life of the tanks floors, eliminate unplanned S/D or emergency incident and avoid corporate maintenance and repair cost.

The promising results of first injection in sour water tank -Figure 3- along with positive feedback from tank operators (Middle east and US) and technical papers, the company management gave a go ahead for the project. For the first phase 21 no tanks were selected.

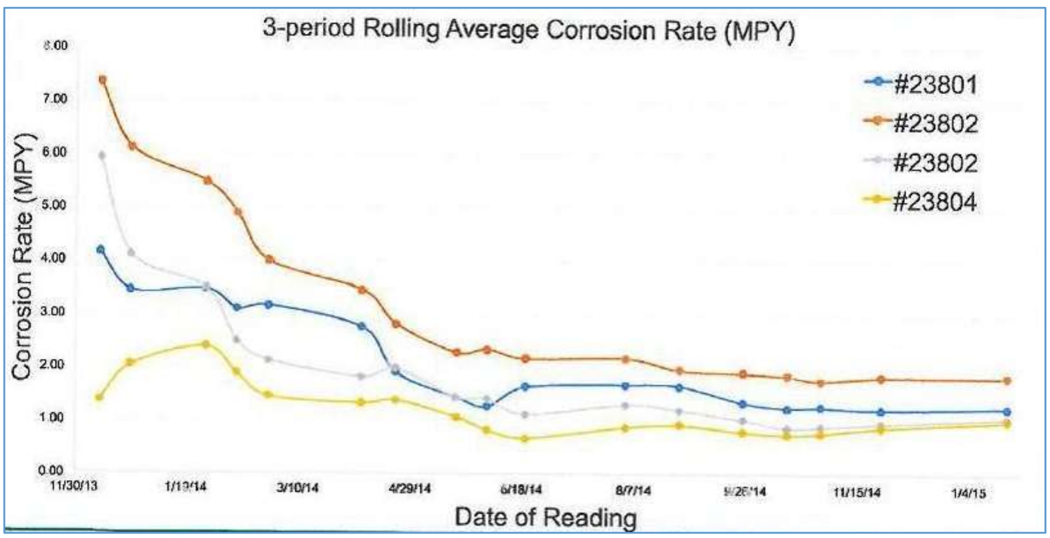

Figure 3: Three-period rolling average corrosion rate(MPY) for Sour Water Tank

The exact location of chemical injection and number of the ER probes was determined during the engineering study. The ER probes were installed in a Polyvinyl Chloride (PVC) pipe under the tank floor with sensing element completely embedded in the sand pad of thank, Figure 4. Data was regularly collected for all tanks pre and post corrosion inhibitor application.

The design scope of work included the following general steps:

1. Installation of Monitoring Device:
   This includes installation of number of electrical resistance (ER) monitoring probes at the numerous location under the tank floor. A minimum of 2 months prior to VPCI injection, reading of ER probes to be collected. The number of monitoring probes depend on the size of tank. The ER probes reading reveal corrosiveness level of the under tank environment without VPCI.

2. Installation of VPCI injection pipes into the interstitial space in such a way that effective distribution of applied VPCI. Injection tubes were installed by core drilling into the bitumen/ Concrete Ring foundation. VPCI Slurry was injected through distributed perforated injection pipes. The pipes are embedded within the sand pad and ensure effective and even distribution of the slurry, such that once applied and migrated the entire bottom plate is controlled, Figure 4.
   Application system to be configured for future online replenishment. Sealing of Annular plate to be applied to avoid escaping out of VPCI or air and moisture ingress into the tank bottom during breathing out.
3. Collection of ER probe Data:
   Corrosion Probes (ER) readings were collected and the efficacy of VPCI were evaluated by differentiating results between ER probes reading prior VPCI injection and after.

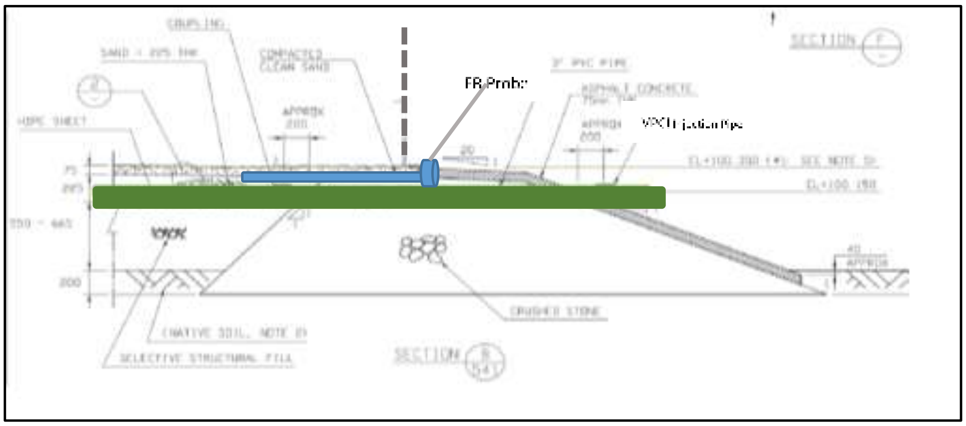

Figure 4: Typical ER probes installation with grout removed above probe location

RESULTS

Significant reduction in corrosion rate is now clearly identifiable across the majority of ER probes, it is expected that as time progresses the outliers shall also reinforce the success of the project.
ER probes data showed a significant reduction in corrosion rate after injection of VPCI Slurry, with average percentage reduction for all probes to be 70%.
Sample ER probes metal loss charts and 3-period rolling average corrosion rate charts for two tanks are displayed in Figure 5 and Figure 7. The pre-and-post injection trend lines are clearly separated with a vertical dotted line.
The decline in corrosion rate trends confirm the functionality of the ER probes. The corrosion rate data was treated by using a three-day moving average as shown in Figure 6 and Figure 8. Data after injection of VPCI illustrates a reduction in the corrosion rate and ends up to a common corrosion rate.
Table 1 clearly defined the efficacy of the VPCI slurry in protecting two tanks by evaluating 10 no. of ER probes before and after injection. The achieved data declare a satisfactory success of VPCI in minimizing soil-side corrosion by reduction in corrosion rate prior and after injection. It is important to mention that diffusion of VPCI to reach metal surface to be protected is a time process and is dependent on the aeration degree of the under tank soil. That is the reason why VPCI action is not instantaneous and takes some time to be visible through ER readings.[3]

Table 1:

Corrosion rates and calculated inhibitor effectiveness

Tank	Probe	Pre-Injection Corrosion Rate (MPY)	Post Injection Corrosion Rate (MPY)	% Efficiency
TK-02	#2731	1.09	0.25	77%
	#2732	1.17	0.25	79%
	#2733	1.96	0.27	86%
TK-03	#2829	1.67	0.28	83%
	#2830	1.60	0.36	78%
	#2831	3.44	0.65	81%
	#2832	2.21	0.28	87%
	#2834	10.29	0.74	93%
	#2835	2.82	0.28	90%
	#2836	1.46	0.28	81%

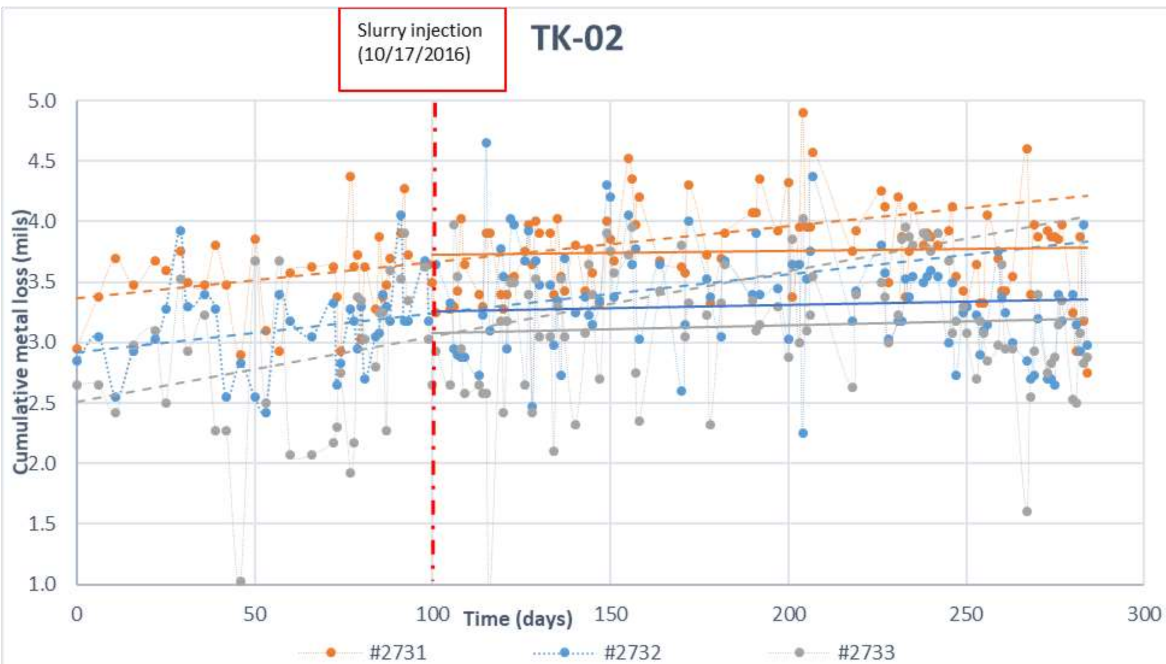

Figure 5: Metal Loss monitoring graph for ER probes in TK-02

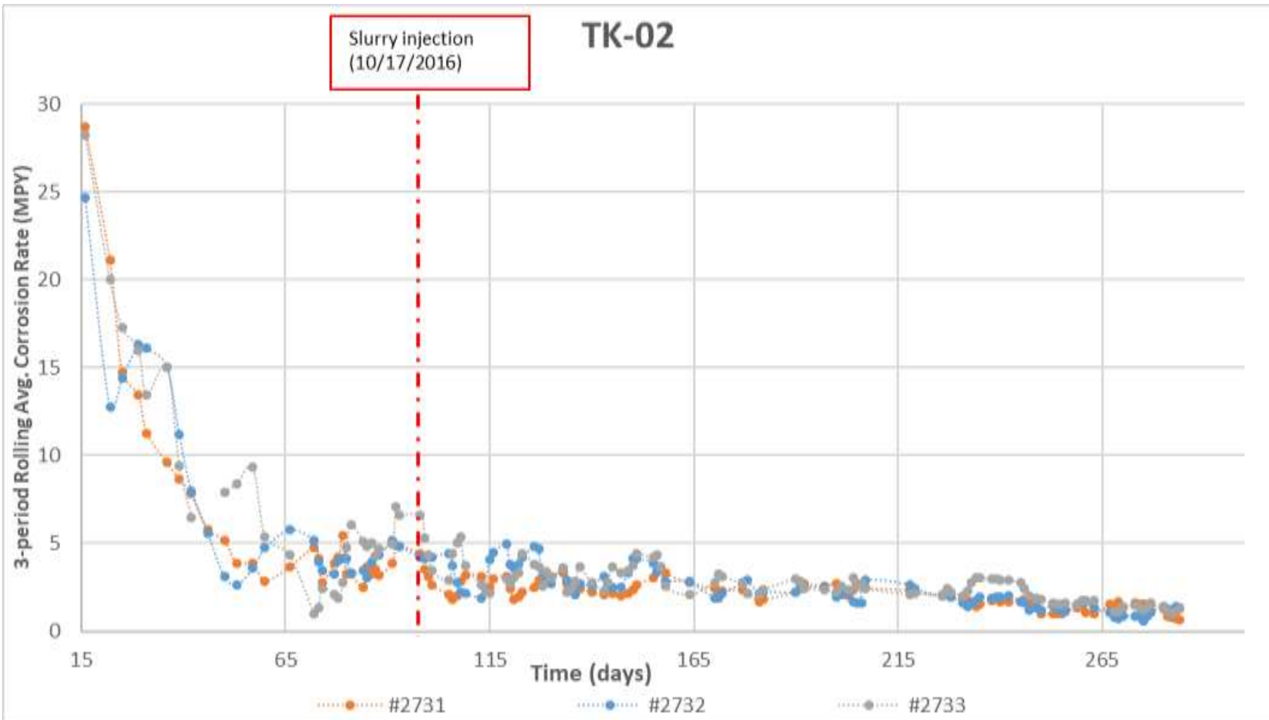

Figure 6: Three-Period Rolling avg. Corrosion Rate of ER probes in TK-02

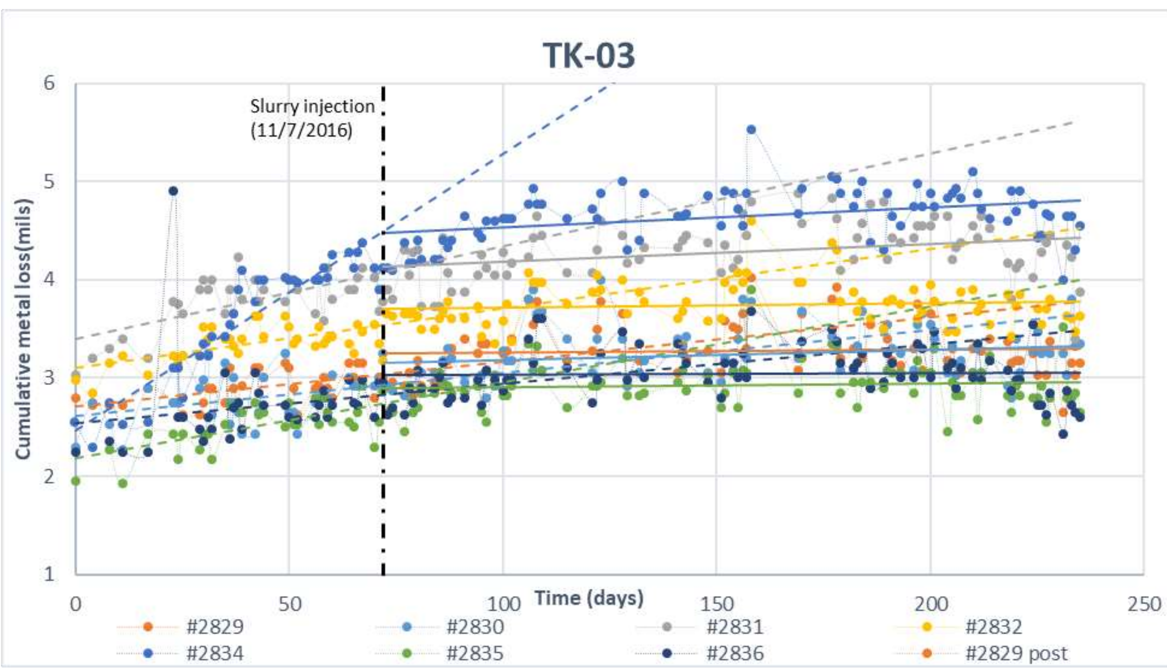

Figure 7: Metal Loss monitoring graph for ER probes in TK-03

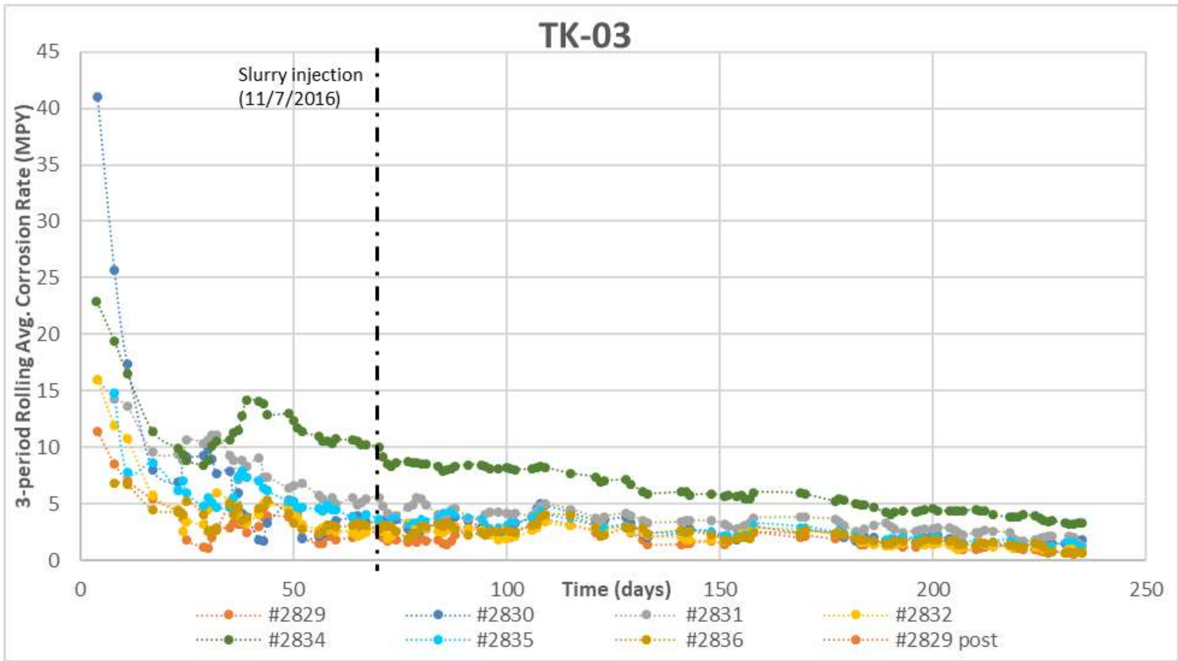

Figure 8: Three-Period Rolling avg. Corrosion Rate of ER probes in TK-03

COST SAVINGS

A business case was presented to the refinery management for 40 tanks that were identified for the project.

The business case presented was based on the following assumptions:

- Tank bottom plate condition is not known as no inspection has been done till date.
- The chemical injection is to extend the life of the tank bottom plates. Hence, some plates may have been already corroded to an extent of complete replacement.
- Bottom plate repair strategy is either by jack-up and complete rebottoming or inspection and patch repair.
- The cost of both these methods vary upon the size (diameter) of the tank to be repaired/replaced, with rebottoming cost almost 4-5 times patch repair cost.

Therefore, even after chemical injection, some repair is anticipated and following assumptions are used for cost savings calculation

- 8 nos. tank (20% of total tanks) may require rebottoming & jack-up
- 32 nos. tank may require patch-up, but not to an extent as required without any chemical injection.

The following table shows the difference of repair cost either by replacing bottom floor or by patching repair and injecting VPCI underneath of 40 tanks.

Table 2:

Cost Saving for VPCI vs floor replacement/Patch repair of total 40 AST Tanks

Cost Savings for Chemical Injection of 40 Tanks	
Cost Description	Cost (USD)
Typical Cost of Re-bottoming 8 tanks (A)	10,400,000
Typical Cost of Patch repair 32 tanks (B)	6,240,000
Typical Cost of Chemical Injection for 40 Tanks (C)	2,808,000
Typical Saving for 40 tanks [(A+B)-C]	13,832,000

The benefits of using VPCI rather than a repair route are in following:

- Technical/Operations: The project has reduced the risk of plant slow down or shut down as the reliability of tanks has increased.
- Integration focus: Implementation of lessons learned from existing plants to growth projects.
- Financials: Savings by avoiding major replacements which include specialized services, revenue when plants reliability and availability increase.
- Human Resources: Savings by reducing the manpower requirements required for jacking-up and replacing the bottom plate
- Corporate Responsibility: Prevent the unexpected leakage of hydrocarbons to the ground bed and also surrounding environment, which maybe a safety and environment hazard.

CONCLUSION

Engineered systems utilizing VPCI technology offer an important supplement for mitigation of tank floor corrosion. These systems are economical, effective, and can be installed on a retrofit basis without disrupting tank service. The reading of corrosion rate data provides confidence that if the VPCI chemistry is effectively delivered under the tank bottoms, and if the intrusion of fresh air and water under the tanks is eliminated, soil-side floor plate corrosion will be mitigated. The results of VPCI project in Suhar conclude the following realities:

- VPCI can be effectively injected underneath of ASTs during on-stream service without any disturbance to operation and Corporate business.
- VPCI can extend the serviceable life of ASTs in case of absence of protection such as insufficient protection from CP.
- ER probes can be used to evaluate the effectiveness of VPCI in reducing soil-side corrosion by exploring the corrosiveness rate of soil environment.
- VPCI accomplishment is a time dependent and related to the soil properties in order to reach complete protection with enough concentration of VPCI.

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