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Evaluation of Impressed Current Cathodically Protected API[1] 650 Tank Bottoms in the Presence of Vapor Phase Corrosion Inhibitor

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ABSTRACT

This work aims to assess the effectiveness of amine carboxylate based Vapor Phase Corrosion Inhibitor (VPCI) on the protection of storage tank bottoms against soil-side corrosion, as standalone and in combination with Impressed Current Cathodic Protection (ICCP) system. It also attempts to determine the effect of VPCI on instant-off potential. Lab-scale tanks simulating the environment of single bottom storage tank sitting on washed sand with High-density polyethylene (HDPE) liner and ICCP system were considered. Corrosion rate for each tank was monitored using Electrical Resistance (ER) probe corrosion monitoring system. Natural and instant-off potentials of tank bottoms' steel plates were also monitored throughout the experiment using temporary Copper/Copper-Sulfate ($Cu/CuSO_4$) reference electrode. Corrosion rate data from ER probes indicated that amine carboxylate VPCI slurry is effective in mitigating corrosion on carbon steel bottom plates. The corrosion rate was reduced by 82.5% and 89.7% as standalone and in combination with ICCP respectively. The study also indicated a shift of the instant-off potential, which might need to be considered by CP operators in the case of using VPCI in supplementing ICCP for protection of storage tank bottoms.

Key words: vapor phase corrosion inhibitor, VPCI, amine carboxylate corrosion inhibitor, impressed current cathodic protection, ICCP, aboveground storage tanks, AST, electrical resistance probes, ER probes, cathodic protection criteria, copper/copper-sulfate reference electrode, $Cu/CuSO_4$, soil-side corrosion

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INTRODUCTION

Soil-side corrosion is a principal cause of storage tank failure and imposes a major environmental and operational challenge worldwide. Several techniques have been adopted to mitigate soil-side corrosion of Aboveground Storage Tank (AST) floors, such as bituminous sand, impressed current cathodic protection and coatings. However, total effectiveness of these techniques, as standalone or combined, have been questionable in providing the required protection, especially against pitting corrosion. *Al-Sulaiman*[1] discussed the possibility of bituminous layer trapping moisture and corrosive species between the underside of tank floor and construction pad resulting in creating a corrosive environment. The author also highlighted the likelihood of bituminous layer when combined with CP to shield protection current and render CP system ineffective, at least partially. *Yu*[2] concluded that inevitable air gaps between construction pad and tank bottom plates block CP current at that location and consequently prevent its uniform distribution on the underside surface of the tank bottom. *Chatterjee*[3] emphasized that underside coating of bottom plates alone cannot prevent corrosion due to unavoidable defects during its application and deterioration during tank operation.

There is a growing industrial awareness about the importance of finding a viable solution to supplement the performance of the aforementioned techniques in an attempt to achieve a comprehensive corrosion protection scheme to the tank bottom. One promising solution is the use of amine carboxylate based vapor phase corrosion inhibitors. Amine carboxylate vapor phase corrosion Inhibitor is a chemical substance that acts to reduce soil-side corrosion by a combination of volatilization from a VPCI material, vapor transport in the headspace between floor plates and the tank pad atmosphere and condensation onto surfaces in the space The condensation process includes adsorption, dissolution and hydrophobic effects on metal surfaces, where the rate of soil-side corrosion of bottom plates' surfaces is thereby inhibited. VPCI material comes in a powder form composed of fine white crystalline amine carboxylate based material infused with silica to eliminate clumping and ensure smooth fogging application through the tank floor. It also comes as a thin liquid solution, delivered into the interstitial spaces under the tank floor through injection pipes placed in the sand layer. During tank construction, VPCI powder enclosed in a pouch constructed from a breathable membrane is used. This breathable pouch allows the VPCI molecules to sublimate through the membrane, diffuse through the sand layer and form a molecular layer on the tank bottom plates providing soil-side corrosion protection.[4]

One of the first publications that confirmed the potential of using VPCI material for soil-side corrosion protection, including pitting, of aboveground storage tank bottoms was written in 1993 by *Rials et al.*[5] Since then, several other published technical articles have recommended and/or confirmed the viability of VPCI as a potential solution for this chronic industrial problem.[4-12] The use of VPCI in protecting tank bottoms against soil-side corrosion has been classically coupled with the use of ER probes to monitor their impact on the corrosion rate data before and after injection. Unlike other indirect corrosion monitoring systems, ER probes are designed to evaluate and continuously monitor the corrosiveness of the surrounding environment under the tank floor. In most cases, ER probes are used as the primary corrosion rate monitoring technique. They are usually installed away from the inhibitor injection point to confirm inhibitor diffusion and evaluate the overall effectiveness of VPCI material.[4,7,8,11,12] However, to our best knowledge, the interaction and effect of introducing such chemicals under the tank floor on instant-off potential of ICCP protected storage tank bottom and soil-side corrosion haven't been investigated.

An experiment was designed to assess effectiveness of amine carboxylate based VPCI slurry in protecting single bottom storage tank bottoms against soil-side corrosion. The experiment also looked into the effect of VPCI slurry on the instant-off potential when installed in combination with ICCP system

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EXPERIMENTAL PROCEDURE

Six lab-scale tanks simulating the environment of single bottom storage tank sitting on sweet sand with HDPE liner and ICCP system were constructed and examined for 120 days. One meter in diameter plastic tanks were cut off their tops and filled with washed sand having average resistivity of 35 000 Ω·cm. Each tank was fitted with a 35 mm in diameter perforated VPCI slurry dispensing ring positioned 100 mm above the tank bottom. Mixed Metal Oxide (MMO) anode grid was placed 270 mm below the steel plate. ER probe was placed about 100 mm below the steel plate. 50 mm in diameter slotted monitoring PVC pipe was also installed in each tank. After compacting and leveling, a 4 mm thick sandblasted round steel plate was placed over the sand. The plates were weighted down with cement blocks and sealed with caulking. An illustration of the test tank design is shown in Figures 1 and 2.

The ER probe selected for this experiment is shown in Figure 3. This probe configuration was chosen for compatibility with the PVC access pipe which was installed under the steel plate of each tank. Data from the probes were taken on a daily basis by connecting to a data logger supplied by the probe manufacturer.

Natural potential of the six tanks was measured and recorded using ($Cu/CuSO_4$) reference electrode. The six tanks were randomly split into two groups; three tanks had their ICCP system activated and the other three hadn't. Input current for ICCP tanks was adjusted to 29 mA until -850 mV instant-off potential was achieved.

The experiment was divided into two phases; pre-injection and post-injection of VPCI slurry. During pre-injection phase, corrosion rate data was collected and natural potential for unprotected tanks and instant-off potential of ICCP tanks were monitored for 45 days. When steady state was achieved, tanks were opened and the status of each steel plate was photographed. Plates were put back into their original place and sealant was reapplied. VPCI slurry was injected through the preinstalled dispensing ring in all tanks. Effect on metal loss of ER probes and instant-off potential of steel plates was monitored for 75 days.

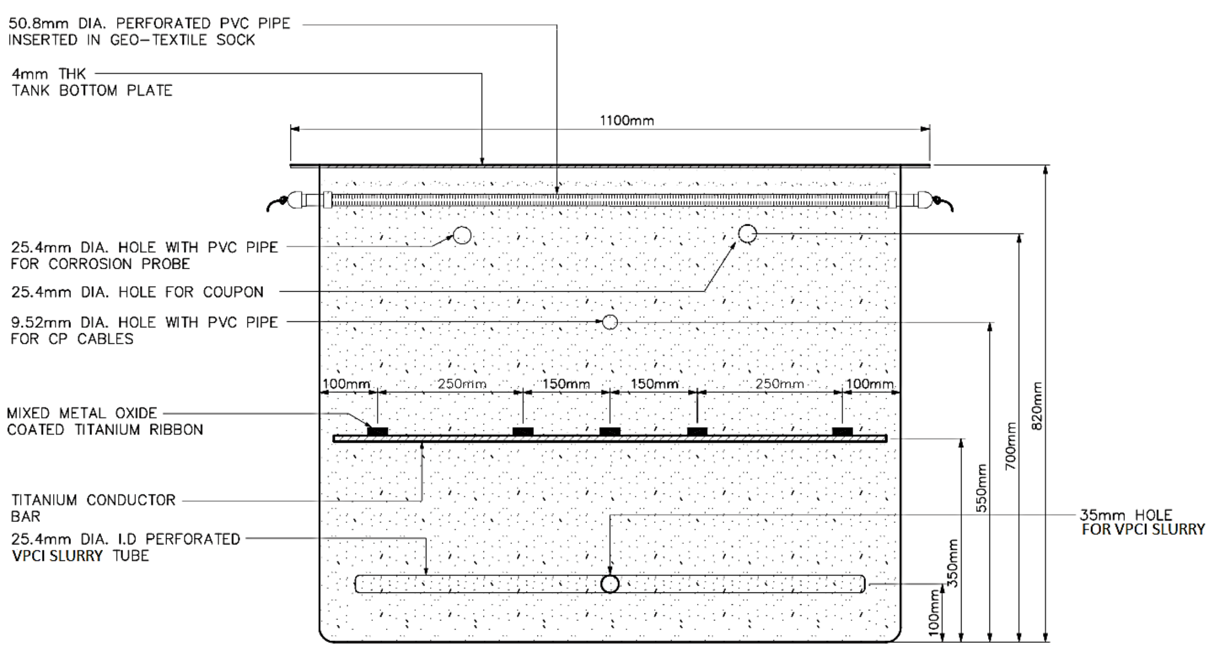

Figure 1: Section view of lab-scale tank

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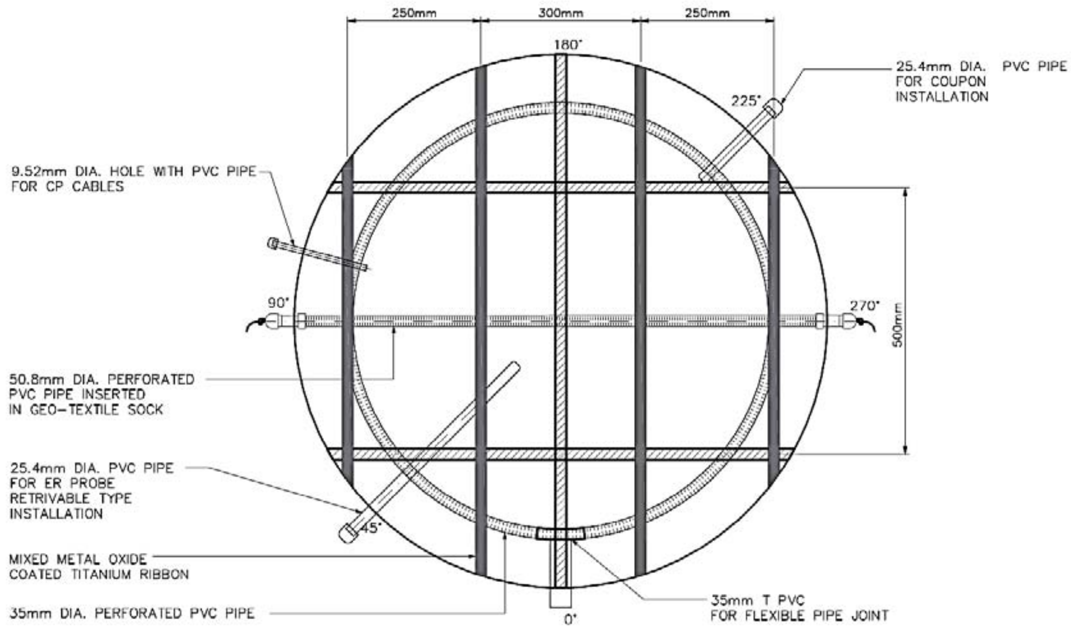

Figure 2: Plan view of lab-scale tank

Figure 3: Electrical resistance probe used for the experiment

RESULTS

Pre-Injection Phase

Natural potentials of unprotected tanks (TK-01, TK-02, and TK-03) continued to shift in the negative direction until it stabilized at an average of -551 mV after approximately 20 days (Figure 4). Corrosion rate data from ER probes installed in non-CP protected tanks showed an average corrosion rate of 15.5 mpy as calculated per Equation 1 from Figure 5. The high corrosion rates from the ER probes were confirmed by the actual status of the steel plates. Upon removal of the steel plates of the unprotected tanks, it was observed that the internal surfaces were covered with sand and corroded, especially at the center area (Figure 6). ICCP protected tanks (TK-04, TK-05, and TK-06) showed average instant-off potential of-1024 mV (Figure 7), satisfying the -850 mV instant-off protection criteria. Corrosion rate data from ER probes installed in control tanks showed an average corrosion rate of 3.2 mpy as calculated per Equation 1 from Figure 8. The low corrosion rate is in line with the fact that protection criteria was achieved. However, visual inspection of underside surface of the plates revealed considerable levels of corrosion (Figure 9). Despite meeting the -850 mV instant-off protection criteria, the actual status of the underside surfaces showed otherwise. The corrosion morphology looked similar to the unprotected tanks.

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This might be attributed to the fact that CP system was not commissioned during and after the construction of tanks for a period of about two weeks. Similar challenge, even on a larger scale, exist in real life, where tanks take from several months to years to be boxed up and their CP system to be commissioned. Tank bottom plates are usually left without any protection during this time. In other cases, lack of availability of power supply hinders activation of CP system for several years in some job sites.

$$CR = \frac{M2 - M1}{\Delta T} \times 365 \qquad (1)$$

ΔT being the lapse time in days between total metal loss between $M1$ and $M2$

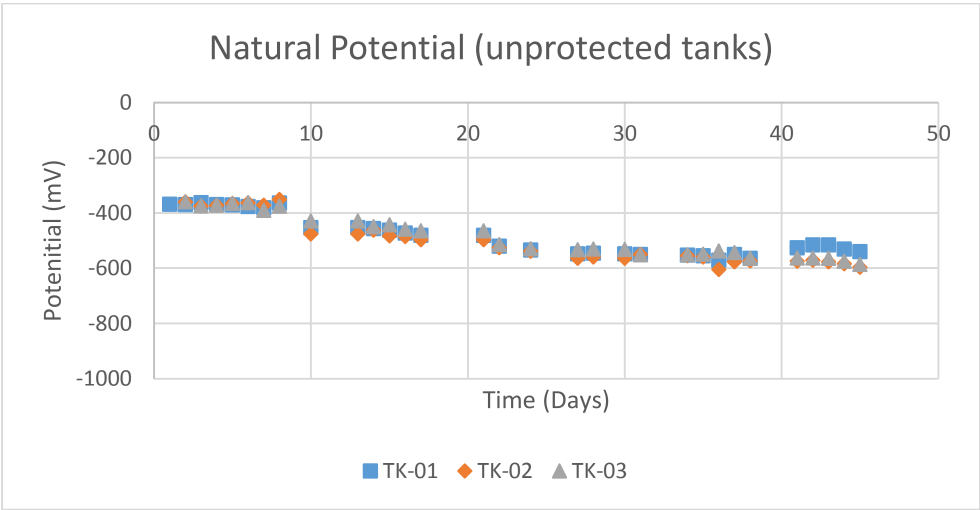

Figure 4: Natural potential of unprotected tanks during pre-injection phase

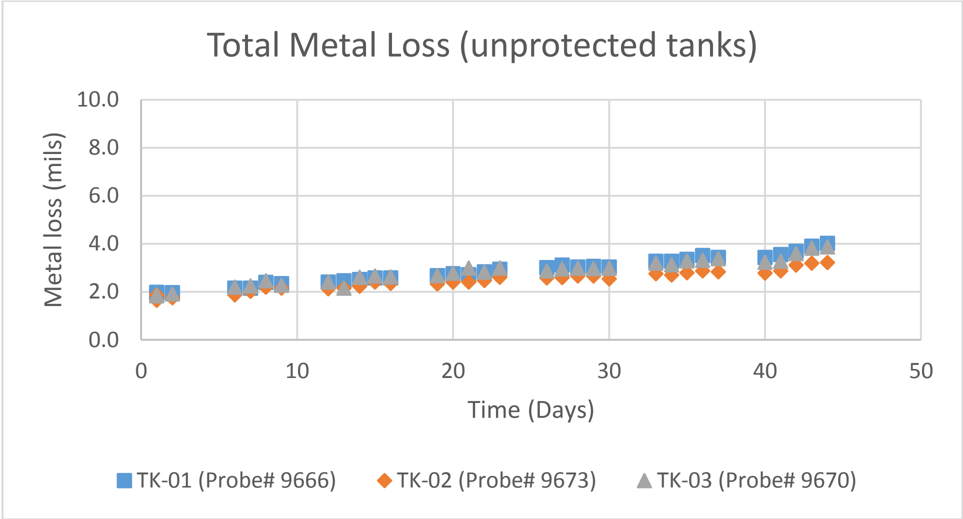

Figure 5: Total metal loss of ER probes installed in unprotected tanks during pre-injection phase

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Figure 6: Underside steel plate of unprotected tanks at the end of pre-injection phase

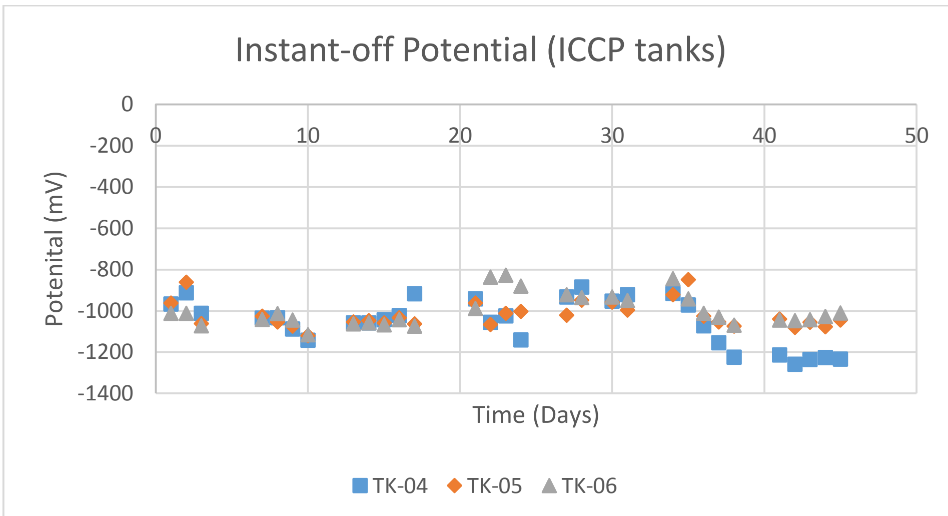

Figure 7: Natural potential of ICCP protected tanks over time during pre-injection phase

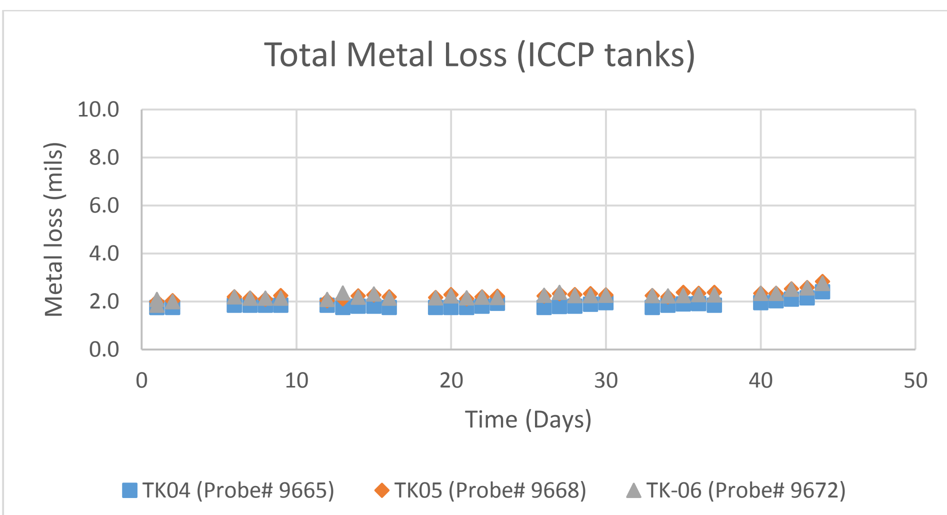

Figure 8: Total metal loss of ER probes installed in ICCP protected tanks during pre-injection

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Figure 9: Underside steel plate of ICCP protected tanks at the end of pre-injection phase

Post-Injection Phase

After injection of VPCI slurry through the dispensing ring, a noticeable effect was observed on the metal loss of ER probes in both unprotected (Figure 10) and ICCP protected tanks (Figure 11). Average corrosion rate of ER probes installed in TK-02 and TK-03 reduced from 13.1 mpy to 0.66 mpy, with average percentage reduction of 95%. However, corrosion rate in TK-01 didn't reflect the same level of effect after VPCI application where corrosion rate was reduced from 15.44 to 6.39 mpy, 59% reduction only. For ICCP protected tanks, average corrosion rate of ER probes went from 3.2 mpy to 0.3 mpy, with average percentage reduction of 90%. It is worthwhile noting that introduction of VPCI slurry under the tank plate helped maintain average corrosion rate under 1 mpy in all tanks, excluding TK-01. Table 1 summarizes the corrosion rates of the individual ER probes before and after VPCI application. It is worthwhile noting that the reduction in the corrosion rate of all ER probes did not only confirm the ability of VPCI molecules to diffuse through a compacted sand layer over a short period of time and protect the underside of tank floor, but also its ability to diffuse through the corrosion product layer on the tank floor and hence reduce corrosion rate of pre-rusted steel.

It has been noticed that VPCI slurry shifted the average potential of unprotected tanks from -550 mV to -500 mV (Figure 12). For ICCP tanks, each tank reacted differently to the VPCI slurry (Figure 13). In tank TK-05, the average instant-off potential shifted temporarily from -1020 mV, before injection, to – 1205 mV for the first 19 days before it started to go back to the original value until the end of the experiment. TK-06 showed also a transient behavior, where its instant-off potential shifted in the negative direction from an average of -1000 mV to reach a value of -1300 mV on day 16 after injection. However, the instant-off potential shifted in the positive direction to stabilize at an average of -1200 mV until the end of the experiment. Prior to injection of VPCI slurry, TK-04 showed average instant-off potential of -1004 mV for about 36 days. A sudden shift in the negative direction of the instant-off potential was noticed on day 37 and continued for 7 days before injection of VPCI slurry to reach -1318 mV. After introduction of VPCI slurry no clear change was noticed until the end of the experiment. However, if average instant-off potential for all tanks was considered before and after injection in Figure 13, it can be concluded that an overall shift of 150 mv in the negative direction was noticed. Although, the findings might not be conclusive in terms of an exact value of the potential shift and whether this shift is permanent or transient, the CP operator can expect a shift in the instant-off potential of the protected tank. Therefore, a longer study should be conducted to answer such queries.

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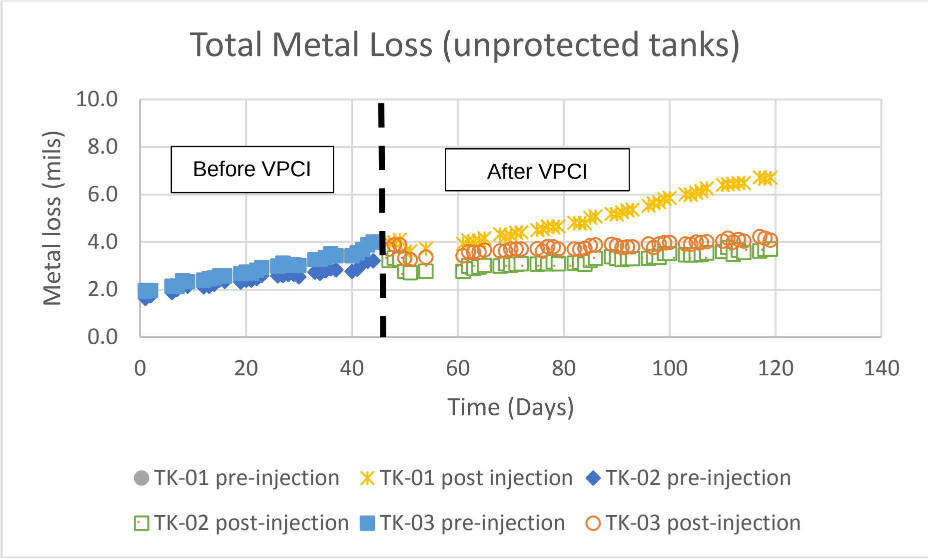

Figure 10: Comparison between total metal loss of ER probes installed in unprotected tanks before and after injection of VPCI slurry

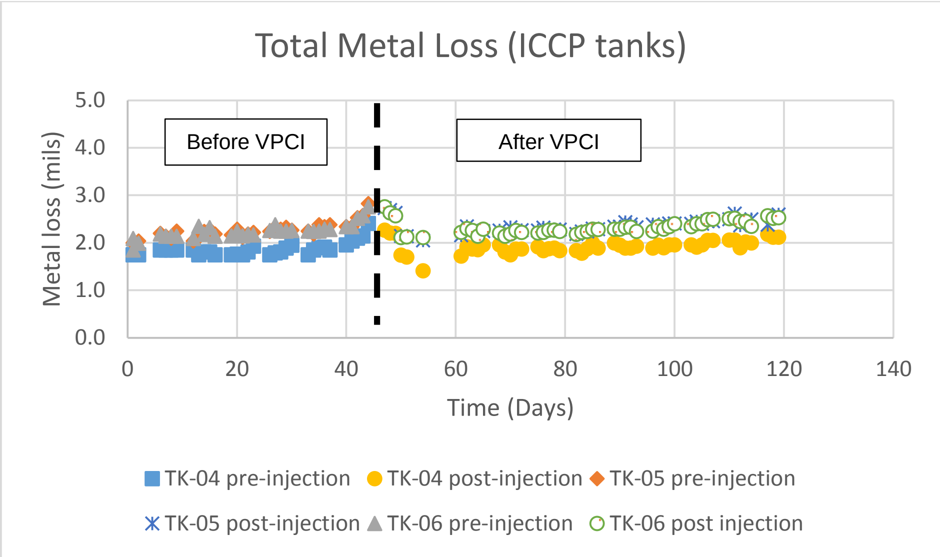

Figure 11: Total metal loss of ER probes installed in ICCP tanks before and after injection of VPCI slurry

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Table 1
Corrosion rate data results

Tank Category	Tank Tag # and Probe ID	Corrosion Rate Before VPCI Application (mpy)	Corrosion Rate after VPCI Application (mpy)	Percentage of Corrosion Rate Reduction After VPCI Application
Unprotected tanks	TK-01 (probe # 9666)	15.44	6.39	58.6%
	TK-02 (probe # 9673)	10.73	0.91	91.5%
	TK-03 (probe # 9670)	15.44	0.40	97.4%
ICCP tanks	TK-04 (probe # 9665)	2.52	0.29	88.4%
	TK-05 (probe # 9668)	3.80	0.29	92.3%
	TK-06 (probe # 9672)	3.50	0.40	88.5%

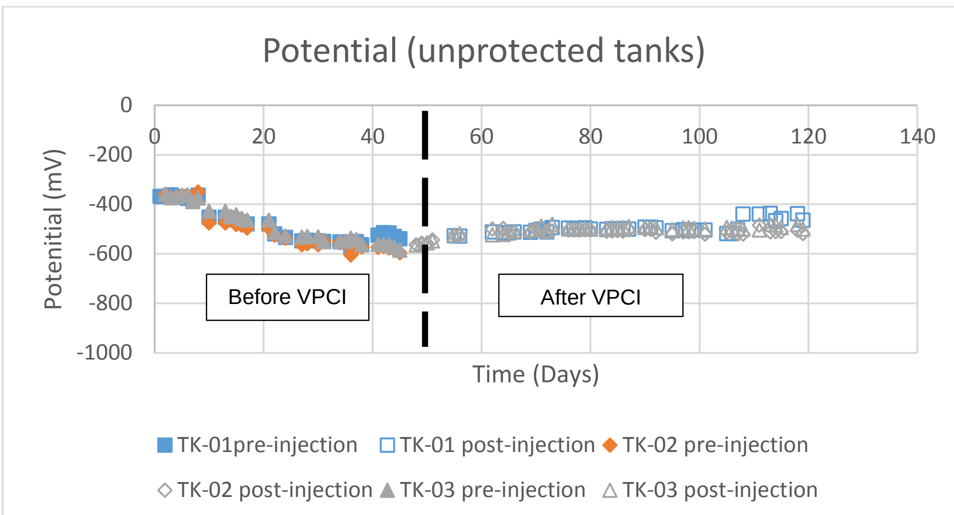

Figure 12: Change in potential of unprotected tanks before and after injection of VPCI slurry

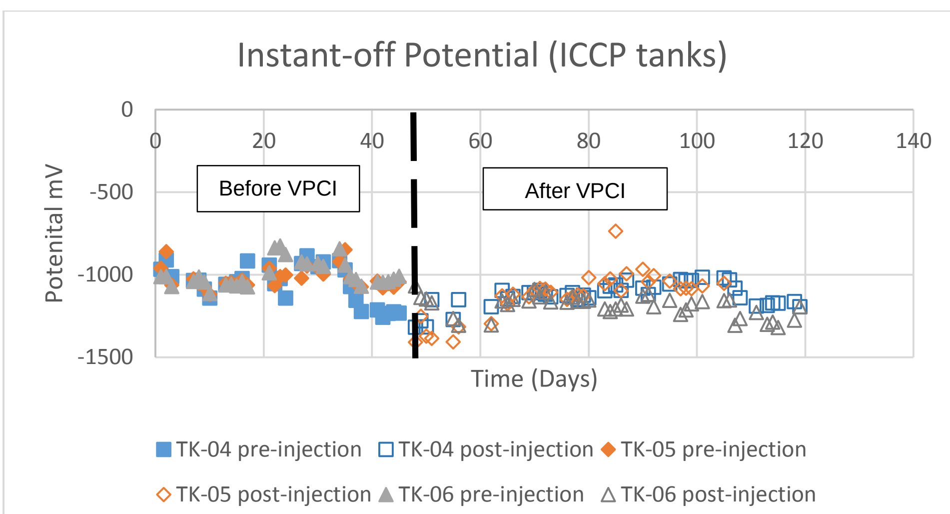

Figure 13: Change in instant-off potential of ICCP tanks before and after injection of VPCI slurry

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CONCLUSIONS

Soil-side corrosion on aboveground storage tanks, including CP protected ones, can present a chronic challenge to operating companies. There is a growing industrial awareness about the importance of finding a viable solution to supplement the performance of the aforementioned technique. One promising solution is the use of amine carboxylate based vapor phase corrosion inhibitor. This experiment was designed to assess the effectiveness of amine carboxylate based VPCI system on the protection of storage tank bottoms against this type of corrosion as standalone and in combination with impressed current cathodic protection system. The experiment also aimed at looking into the effect of VPCI slurry on the instant-off potential and in turn the protection criteria of ICCP system. The obtained results allow us to draw the following conclusions:

- Despite having a CP system satisfying the protection criteria of -850 mV instant-off potential, the tanks showed signs of soil-side corrosion. This might be partially attributed to CP system not being commissioned as soon as the tanks were constructed allowing the corrosion process to start. Due to the spontaneous protection mechanism of amine carboxylate VPCI system, it might be advantageous to introduce amine carboxylate VPCI material into the tank sand pad to provide protection of the underside of tank bottom plates during construction and until CP system gets commissioned.
- Electrical resistance corrosion rate probes can be used to evaluate the corrosiveness of the environment under AST and indicate the effectiveness of VpCI in reducing and controlling soil-side corrosion.
- VpCI Slurry can be effectively introduced and distributed through a designed online injection system under existing and new aboveground storage tanks.
- VPCI slurry alone showed the ability to reduce corrosion rate by 82.5%, which makes it a viable solution to protect against soil-side corrosion, especially for tanks without CP system or when existing CP system is deficient.
- VPCI slurry in combination with ICCP showed a synergetic effect on corrosion rate and helped maintain the corrosion rate below 0.5 mpy with an average reduction of 89.7%, which suggests the concept of supplementing new and existing CP system with VPCI material is therefore advantageous to operating companies.
- Introduction of VPCI slurry may have an effect on instant-off potential and this might need to be considered by CP operators in the case of using VPCI slurry in supplementing existing ICCP system. However, an experiment for longer duration or actual field trials is required to confirm the value of this effect and whether it is transient or permanent.

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