Chapter 10

Vappro VBCI Anti-Corrosion Management Program for Above Storage Tank (ASTs) and Underside of Bottom Plate in the Absence or Deficiency of CP System

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Background

Protection of above-ground oil storage tank bottom plates against soil-side corrosion is an important concern for the oil and gas industries, especially in continuous operation requirements for these assets.

Any effective corrosion control measures must be taken to ensure the integrity of the bottom plate for continuous, safe, and economical operation of storage tanks.

One of the most commonly used corrosion protection methods is a cathodic protection (CP) system. However, it is well-accepted that CP alone may not be enough to achieve the required level of protection.

American Petroleum Institute (API) Standards 650, 651, 652, 653, and 620 are the primary industry standards by which most ASTs are designed, constructed, and maintained.

Since there are no stated requirements under API 650 for corrosion allowance, that decision is left to the oil companies.

Hence, any use of VCI products to supplement the CP system must be accompanied by an online corrosion monitoring system to achieve the continuous, safe, and economical operation of the storage tank.

The durability of ASTs is assured by solid specifications for the construction phase and can be improved through good operation and maintenance practices through Vappro VBCI anti-corrosion management program.

A propitious alternative industrial practice is the use of Vappro VBCI and Vappro CRI products under tank bottoms to either supplement existing CP systems or provide protection in its absence.

The Vappro anti-corrosion management program for ASTs aims to ascertain the effectiveness of Vappro VBCI and CRI products to protect oil storage tank bottoms against soil-side corrosion while in service and during construction of new ASTs.

It was assumed that the oil storage tanks are sitting sweet sand pad with an inactive CP system.

The effectiveness of Vappro VBCI and CRI products can be determined through corrosion rate monitoring using Vappro CCMS (corrosion control monitoring system) together with electrical resistance (ER) probes.

Corrosion rate can be monitored over a 24-month duration in the test tank with relative humidity above 85%. At the end of the test period, selected exposed ER probe element will be subjected to visual inspection and spectroscopic and structural analysis to explore the passivation effect of VBCI, CRI products, and correlate the results with ER readings.

Extenuation of Soil-Side Corrosion of Above-Ground Storage Tank (ASTs) Bottom Plates

Different methods, as stand-alone or in combination, have been adopted to control soil-side corrosion of bottom plates, such as proper foundation design, placement of special backfills, and construction using corrosion-resistant alloys, coatings, and CP systems. Each one of these methods has its own performance and limitations; some of them are briefly discussed hereunder.

Cathodic protection to underside of tank bottom plates can be provided by sacrificial galvanic anodes or by an impressed current cathodic protection (ICCP) system. The use of galvanic anodes is limited to small tank diameters and for soil resistivity of 5,000 Ω.cm or less. When more current or longer design life is required, ICCP is preferred.

However, in both systems, electrical current flow between the anode and the cathode should be maintained to provide adequate protection. For instance, the presence of aggregates was found to cause a CP deficiency by preventing a uniform CP current flow, leading to severe corrosion.

The same finding was observed in the case of an oily sand pad where its high electrical resistivity shielded CP current flow and affected uniform distribution throughout the tank floor plate surface.

Moreover, filling and refilling of the storage tank and weld overlaps created air gaps between the tank bottom plates and the tank foundation, which consequently prevented the CP current from reaching to the bottom plates in these areas.

According to a survey carried out in 2012 at an oil and gas facility in the Arabian Peninsula, randomly selected tanks showed that soil-side corrosion was present on all CP-protected and non-CP-protected tanks.

It also showed that air gaps between bottom plates and foundations were detected in all tanks and that the measured CP potential during the annual CP survey was not representative of the bottom plate condition. In addition to an ICCP system, the use of protective coatings on the soil side of tank bottom plates is often considered.

However, these are always prone to pinhole defects during application and damage during installation and at weld joints. They are also subject to inevitable ageing process over time, leading to delamination and undercoating corrosion.

Due to the wide variety of soil conditions and tank hydrostatic pressures, different construction pads have been considered such as continuous asphalt, concrete, oily sand, and washed sand.

Due to ageing, all these foundations provide limited degree of protection and remain susceptible to ingress of corrosion species from soil such as moisture, chlorides, and microorganisms.

The use of a double-bottom design with containment of high-density polyethylene (HDPE) liner is one of the practices where the use of CP is necessary, and anodes should be installed between the upper and lower floor or containment liner. For this type of design, CP is problematical to maintain or repair.

Vappro VBCI-Volatile Corrosion Inhibitor (VCI) for AST Bottom Plate Protection

Vappro VBCI volatile corrosion inhibitor is a chemical substance that acts to reduce soil-side corrosion by a combination of volatilisation from the VCI media, vapour transport in the headspace between floor plates and the tank pad atmosphere, and adsorption on to surfaces in the space.

The inhibition mechanism involved includes adsorption, dissociation, and hydrophobic effects on metal surfaces, where the rate of soil-side corrosion of bottom plate surfaces is thereby inhibited.

VCI chemistry comes in different forms to fit different application methods in protecting AST bottom plates. It comes in powder form and can be delivered by fogging application through the tank floor while it is out of service.

VCI chemistry is also available as a thin solid–liquid solution that can be delivered into the interstitial spaces under the tank floor through injection pipes placed in the sand layer while the tank is in service.

During tank construction, Vappro 830 VBCI Pouch–VCI powder enclosed in a pouch constructed from a breathable Tyvek membrane can be placed immediately on top of the HDPE liner. Vappro VBCI breathable pouch allows the VCI molecules to be emitted through the membrane, diffuse through the sand layer, and form a molecular layer on tank bottom plates, providing soil-side corrosion protection during and after the construction of the tank.

The utilisation of organic-based VCI in the protection of AST bottoms against soil-side corrosion started in 1986, as published in Rials *et al.* in 1993, a technical paper discussing the use and effectiveness of VCI to control soil-side corrosion of above-ground storage tanks with secondary containment, such as double-bottom tanks.

The study suggested that VCI is effective in controlling corrosion in moisture-saturated conditions, especially pitting corrosion when compared to an ICCP system.

Gandhi discussed research and fieldwork that indicated VCI can protect bottoms of storage tanks over 15 years and can be used in conjunction with the traditional CP corrosion control methods.

Expected service life of the initial corrosion inhibitor installation depends on the dosage rate, delivery method, distribution, and enclosure of the inhibitor. In the Middle East, the first published recommendations to use VCI for underside AST bottom corrosion was in 2010 initiated by Yu and in 2012 by Barnawi.

In 2013, Whited *et al*. discussed a successful pilot project on the use of VCI in protecting a very large 107.4-meter-diameter crude oil storage AST, with oily sand pad, located at a tank farm in the eastern Arabian Peninsula. The effectiveness of VCI against soil-side corrosion is generally demonstrated through the online monitoring of corrosion rate with and without VCI by using ER probes installed in the under-tank environment.

On this basis, Vappro CCMS and its ER probes can be used to indicate the need for future VCI replenishment. 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 than the bottom-plate potential using reference electrodes, which can suffer from ohmic drop, causing reading errors.

It was based on the above journal citations that Magna International together with its think tank group based in Universidad Autonoma de Baja California proposed the preservation of the underside bottom plate of oil storage tank as mentioned below.

Vappro VBCI Preservation Procedure for Bottom Plate of Oil Storage Tank and the Installation of Vappro CCMS, ER Probes for Existing and Construction of New Storage Tanks

Brief

As the tender for said preservation is a tedious and costly process, it is only a prudent approach to award the preservation contract to the company that offers the most comprehensive methodology preservation in terms of most competitive pricing and supplies of the most effective corrosion inhibitors, corrosion monitoring system, and technical support.

Due to the significant potential advantages that Vappro VBCI offers, it would be beneficial for the oil and gas industry to adopt the most effective VBCI technology currently available and use it as another corrosion prevention solution under the corrosion protection platform where the application of cathodic protection is impracticable at the underside of the tank bottoms with liner or spill prevention barriers.

Vappro VBCI Anti-Corrosion Management Program

The Vappro VBCI anti-corrosion management program demonstrates the concept of using Vappro VBCI and CRI products coupled with the use of electrical resistance ER corrosion probes as an online soil-side corrosion control method for oil storage tanks.

Depending whether it is an existing or the construction of a new tank, a combination of Vappro VBCI products—Vappro 849 VBCI Powder, Vappro 830 VBCI Pouch, and Vappro CRI CAT 8000—can be employed for the preservation of said tanks.

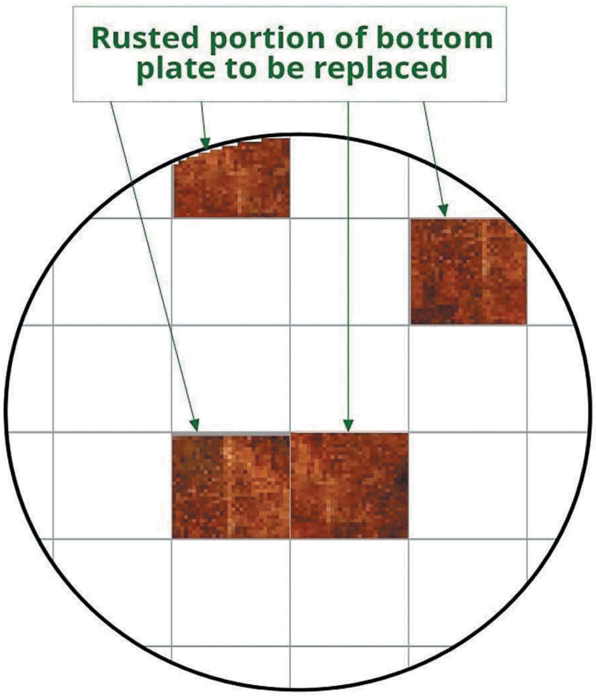
Preservation Procedure for the Underside of the Bottom Plate of Existing AST

PVC conduits are to be installed in the sand base underneath the bottom plate to install electrical resistance (ER) probes.

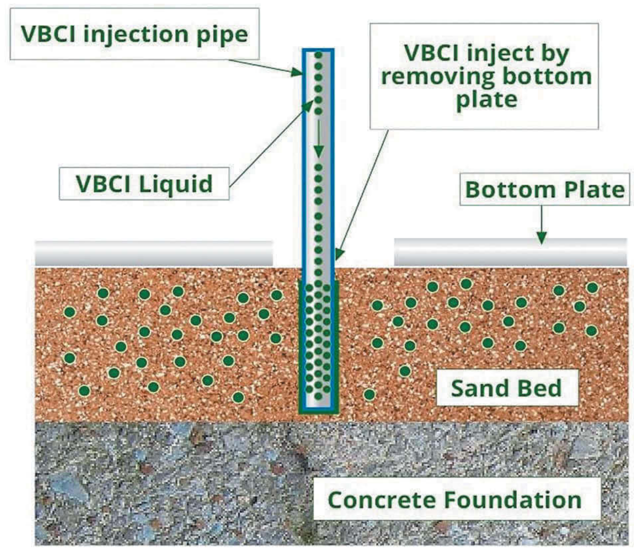
The Vappro CRI 800 or Vappro 849 can be injected under all the floor plates by drilling injection holes in the floor plates or during repair and replacement of the floor plates.

The said Vappro products may be injected using high-pressure systems to push CRI liquid VBCI powders into the soil bed and create a corrosion-inhibiting environment. Inject Vappro VBCI Liquid into sand base till sand base is saturated concrete floor for the existing tanks.

Bottom Plate Injection System



Picture 1



Picture 2

The plates that are marked rusted brown as shown in figure 1 are corroded portions of the bottom plate and required to be replaced. The Vappro VBCI Liquid inhibitors are injected under the plates during the said replacement.	Vappro VBCI Liquid is injected via pressure through the VBCI injection pipe as shown in picture 2 above.

Underside Injection

A perforated or slotted tube is drilled under the tank bottom, and Vappro VBCI liquid inhibitor fluid is injected into the sand bed as shown in picture 2. The inhibitor is breathed and moved within the sand bed due to normal breathing action of the tank bed and evaporation of the inhibitor fluid within the bed.

Preservation of New Oil Storage Tank Sand Bed

It is always advisable to use Vappro VBCI Protection right from the beginning at the time of construction. This improves inhibition efficiency as well homogeneity in the base-plate protection and the rebars of the concrete floor foundation.

Contrary to common belief, concrete itself is a complex composite material. It has low strength when loaded in tension, and hence, it is common practice to reinforce concrete with steel, for improved tensile mechanical properties.

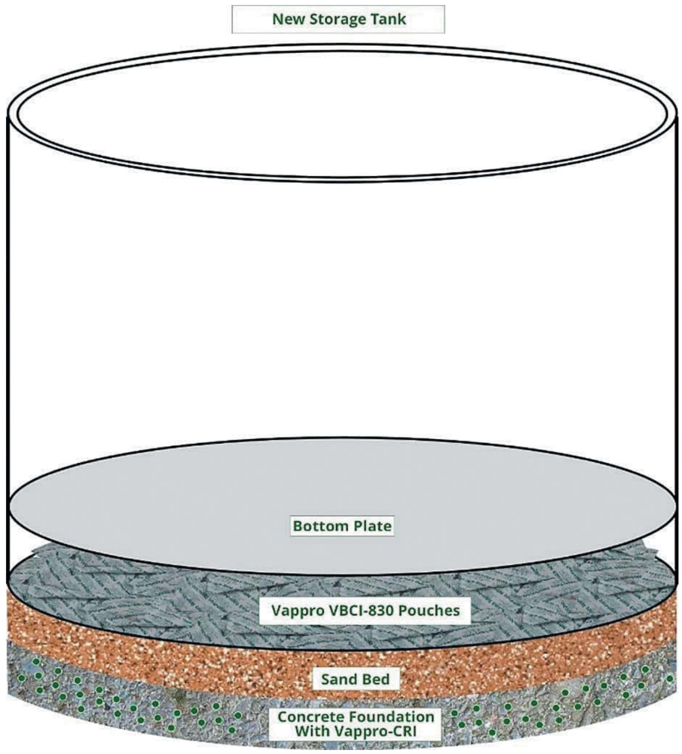
Concrete structures such as concrete foundation of storage tanks, bridges, buildings, elevated highways, tunnels, parking garages, offshore oil platforms, piers, and dam walls all contain reinforcing steel (rebar).

The principal cause of degradation of steel-reinforced structures is corrosion damage to the rebar embedded in the concrete. Iron is unstable in nature, and because reinforcing steel used in precast concrete is made largely of iron, it too becomes unstable when exposed to corrosive agents such as salt, carbonation, and even air.

Vappro CRI 8000 is a free-flowing liquid concrete admixture utilising a vapour corrosion inhibitor to protect steel reinforcing, carbon steel, galvanised steel, and other metals embedded in concrete. Corrosion induced by carbonation, chloride, and atmospheric attack can be prevented with the use of Vappro CAT 8000. When added into the concrete mix, Vappro CRI 8000 works by diffusing the VCI ions on to the surfaces of rebars, forming a molecular layer of corrosion-inhibiting layer on it.

In view of the above, Vappro CRI 8000 is highly recommended to be developed to combat the said problem in the abovesaid structures.

The Vappro VBCI chemicals should be placed closest to the metal surface. Therefore, after forming the base of sand/gravel, the VCI chemical may be spread on the base by manually spreading or sprinkling. The tank bottom may be directly placed, touching Vappro VBCI 849 powder or Vappro 830 VBCI Pouch for highest effectiveness.



Picture 3

Introduction of the Usage of Vappro CCMS and Electrical Resistance Monitoring (ER)

The Vappro CCMS electrical resistance (ER) technique is an 'online' method of monitoring the rate of corrosion and the extent of total metal loss for any metallic equipment or structure.

The Vappro CCMS ER technique measures the effects of both the electrochemical and the mechanical components of corrosion such as erosion or cavitation. It is the only online, instrumented technique applicable to virtually all types of corrosive environments.

Although universally applicable, the ER method is uniquely suited to corrosive environments having either poor or non-continuous electrolytes such as vapours, gases, soils, 'wet' hydrocarbons, and non-aqueous liquids.

Examples of situations where Vappro CCMS and ER approach is useful are:

- oil/gas production and transmission systems
- refinery/petrochemical process streams
- external surfaces of buried pipelines
- feed-water systems
- flue gas stacks

The instrument may be permanently installed to provide continuous information or may be portable to gather periodic data from a number of locations. The probe is equipped with a sensing element having a composition similar to that of the process equipment of interest.

Electrical Resistance (ER) Probes

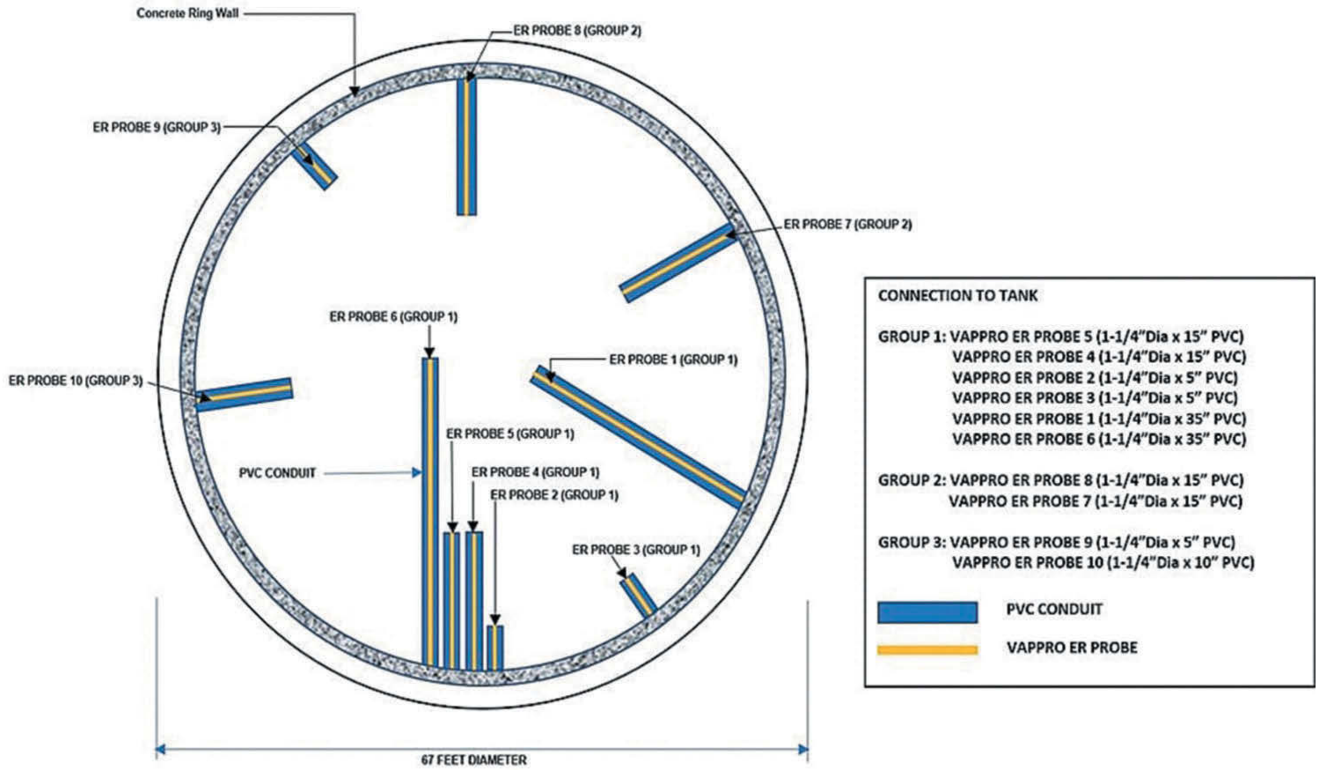
Corrosion rate monitors may use electrical resistance (ER) probes. Electrical resistance (ER) probes are inserted into the sand or soil foundation to measure the corrosivity of the underlying environment. Baseline corrosion rates are determined by monitoring the change in resistance over time detected by the ER probes.

The vapour emitted from the Vappro VBCI protects the ER probes, demonstrating the effectiveness of the Vappro VBCI products. ER probe tubes are installed in various points to provide estimates of bottom-plate corrosion. The ER probe cables are stored outside.

The probes will be divided into three groups; ten probes were positioned at different locations underneath the tank bottom as shown in Picture 4. These probes are placed very close to the underside of the tank floor. Their test leads were run into junction boxes where data are uploaded into the computer and real-time information is collected.

The corrosion rate will be monitored on all the ten probes. The ER probes represent a small section of the tank bottom with known dimensions (area and thickness) in the sand base. Any active corrosion occurring on the probes will cause reduction in thickness of the probe, and the rate of corrosion can be calculated with change in thickness measurements.

Positioning of the ER Probes of CCMS



Picture 4

Corrosion Rate Trend Before and After the Application of Vappro VBCI

1. After the installation of the probes, collect the probe thickness measurements data (base line) before VBCI is introduced. The period from the time the probes are installed and the time before VBCI is introduced is called the 'no extenuation' period. The 'no extenuation' period is approximately up to two to four months. During the 'no extenuation' period, the probes are let to corrode freely under the sand bed environment.
2. After VBCI chemical is injected, then it is called the 'extenuation' period. The extenuation effectiveness will be measured with the reduction in corrosion rates occurring on the probes.
3. Two corrosion rate threshold limits of 1 mil per year (25.40 micrometre per year) and 2 mils per year (50.80 micrometre per year) will be used to evaluate the VBCI system effectiveness. The VBCI system effective protection levels in terms of corrosion rates (mils per year) are not defined by NACE or any regulatory agencies; however, as an industry practice, the safe corrosion rate of 1 mil per year used for cathodic protection was adopted. Based on the intent and criticality of protection required, a tolerable corrosion rate of 2 mils per year could be used for VBCI applications.

4. After the introduction of VBCI, collect probe thickness measurement data periodically over a period of 24 months.
5. Corrosion rates (mils per year) of the probes can be calculated from the thickness loss measurements via equation 2. The corrosion rates were displayed by the data logger software. Thickness loss is equivalent to metal loss, which is a function of the probe linearised signals and probe life; see equation 1 below.

Calculation of Corrosion Rate Using Thickness Loss from ER Probe

Probe thickness measurements data (baseline) will collect on all the ER probes before the VCI was injected. After Vappro VBCI is introduced, periodic thickness measurement data and corrosion rate will also be collected. The data will be collected over a period of 12 months during the test tank and subsequently every 24 months. Corrosion rates will be obtained from the calculation based on reduction in thickness of various ER probes with time. Corrosion rates (mils per year) of the probes can be calculated from the thickness loss measurements via equation 2.

$$M = \frac{S \text{ x } P}{100} \qquad (\textit{Equation } 1)$$

$$C = \frac{\Delta \text{M x } 365}{\Delta \text{T}} \qquad (\textit{Equation } 2)$$

Where M is metal loss (thickness loss),

S is a linearised signal, which is proportional to thickness loss and is incorporated into the probe life (P),

T is the lapse time in days between readings, ΔM is change in thickness, ΔT is the time it takes to obtain the thickness loss, while C is the corrosion rate.

Conclusion

Depending on the availability of budget of the client, the recommendation for Vappro VBCI products varies to suit the customer requirements. However, Vappro VBCI 849 VBCI Powder and Vappro CRI 8000 Concrete Rebar Inhibitors and Vappro 830 VCI Pouch are highly recommended for the preservation of the underside of the bottom plate of the oil storage tank.

Magna will furnish the corrosion rate trend before and after the application of Vappro VBCI products upon collection of the field data and overall Vappro VBCI system effectiveness for tank bottom protection.