Paper No.
4200

CORROSION 2014
Collaborate. Educate. Innovate. Mitigate.
March 9-13, 2014 • Henry B. Gonzalez Convention Center • San Antonio, Texas, U.S.A.

Protection of Offshore Platform Caisson Legs with a Vapor Corrosion Inhibitor- A Case Study

Talal A. Rahman Al-Sayed
Ahmed Fathi Eid
Mahdi Mohamed Al-Marzooqi

Abu Dhabi Marine Operating Company
(ADMA-OPCO)
United Arab Emirates

Usama Jacir
Cortec Middle East
United Arab Emirates

ABSTRACT

In November 2000, gas build-up inside the confined compartment around an offshore platform caisson leg led to an explosion. The gas was found to be hydrogen generated by the depleted anodes inside the caisson leg. An investigation of the fatal explosion made several recommendations, including removal of the anodes, biocide-treated water and blasting grit that had accumulated inside the caisson legs over two decades.

A pilot study was conducted to evaluate the use of a vapor corrosion inhibitor (VCI) for structure integrity protection after removing the blasting grit and biocide-treated water from one of the legs. Treatment commenced with spraying the internal diameter of the leg with a water-based solution containing a vapor corrosion inhibitor with a biocidal treatment. This was followed by fogging the internals with an amine carboxylate VCI. Finally, a string of pouches containing VCI powder was suspended on hangers to assure continuous saturation of inhibitor in the space. Corrosion coupons were installed 6m below the manhole before closing it.

Results after one year and beyond were positive and the system was adopted for rectification of the problem.

Key words: offshore platform, caisson legs, vapor corrosion inhibitors, amine carboxylate, corrosion

INTRODUCTION

ADMA-OPCO[1] is a major producer of oil and gas from the offshore areas of Abu Dhabi in the United Arab Emirates. It is a partnership between ADNOC[2] (60%), BP[3], Total S.A.[4], and JODCO[5]. It operates two major fields – Umm Shaif and Zakum, where oil and gas is produced and transferred to Das Island for processing, storing, and exporting. Multiple barge-type offshore platforms are constructed and operated on caisson legs.

Internals of the platform caisson legs are uncoated and filled with biocide-treated water and protected using suspended sacrificial anodes. They also contain debris including blasting grit. After two decades of operation, the anodes had been depleted and gas generation led to a fatal accident in 2000 when an explosion occurred inside the confined compartment around a caisson leg of a platform.

A board of inquiry recommended several actions including the removal of the blasting grit and biocide treated water. A multidisciplinary team was assigned to investigate a methodology to maintain the integrity of the caisson legs and mitigate internal corrosion. Several options were considered and assessed for their effectiveness, ease of application, and environmental impact. These included a new grouting and sealing procedure, installation of a glass-reinforced plastic (GRP) pipe and filling the annular space with inhibited cement and others. The final recommendation was corrosion management utilizing vapor corrosion inhibitor (VCI). To assess the effectiveness of this approach, a pilot project was launched in 2009 whereby one caisson leg was emptied and preserved with VCI. Carbon steel weight loss corrosion coupons were used to assess the effectiveness of this approach.

Unlike traditional contact corrosion inhibitors, VCIs have a moderately high vapor pressure that allows them to function in the vapor phase without applying VCI directly to the metal surface.[1-2] Therefore, VCIs provide protection in the liquid phase, vapor phase, and critical interphase. They can access difficult to reach spaces and provide effective protection against crevice corrosion.

Several groups of organic compounds have reported corrosion inhibiting effects. The effectiveness of amine carboxylate VCIs is well documented in lab and field assessments over the last thirty years.[3] Amine carboxylates VCIs are dipoles where charges are not uniformly distributed, allowing them to be attracted and adsorbed to both cathodic and anodic locations of a corrosion cell. Their adsorption to different alloys has been found to fit with the Langmuir adsorption isotherm (Equation 1) with an enthalpy of adsorption of about -10 to -16 kJ/mol.[4] This physical bond on the metal surface creates a monomolecular barrier that protects against aggressive ions. The barrier re-heals and self-replenishes, and can be combined with other functional properties such as binders biocides for added protective capabilities.

$$\theta = \frac{\alpha\ x\ P}{1 + \alpha\ x\ P} \tag{1}$$

θ = fractional coverage of the surface
P = Gas pressure
A = constant

Unlike hazardous nitrite or secondary amine inhibitors, amine carboxylates are salts with mostly neutral pH and relatively low vapor pressure making them an environmentally safe option for corrosion

[1] Abu Dhabi Marine Operating Company, PO Box 303, Abu Dhabi, United Arab Emirates
[2] Abu Dhabi National Oil Company, Corniche Street, PO Box 898, Abu Dhabi, United Arab Emirates
[3] British Petroleum, 1 St. James's Square, London, SW1Y 4PD, United Kingdom
[4] Total S.A., Tour Coupole, 2, lave Jean Millier, Arche Nord-Coupole/Regnault, 92078 Paris La Defense Cedex, France
[5] Japan Oil Development Co., Ltd. Akasaka Biz Tower 5-3-1 Akasaka, Minato-ku, Tokyo 107-6332, Japan

protection. They are also non-flammable and safe to handle and use, which is a considerable advantage especially in the offshore work environment.

Amine carboxylate VCIs have been effectively used for over thirty years in multiple applications including the protection and mothballing of equipment, hydrostatic testing, protection of underside of tank floors, protection of cased crossings, and other applications. Their use in caisson legs while theoretically achievable had not been tried in the past.

METHODOLOGY

The integrity team in charge selected caisson leg WIN 4494 0052 in Umm Shaif Additional Accommodation Platform (USAAP) for the pilot project and recommended protecting the inside of the leg by applying an amine carboxylate VCI. The caisson leg was constructed of carbon steel with 1.80 m in diameter and 20.8 m in length. Three products with different delivery systems were chosen to achieve the desired result.

First, a pipe coater was used to apply Inhibitor A (liquid) on the internal diameter of the leg. This was chosen to provide both contact corrosion inhibition and biocidal treatment for the internal surfaces. Then Inhibitor B (pouch containing powder) was suspended on a stainless steel wire rope down the length of the leg. Inhibitor B is intended to provide a source of VCI to replenish any gaps in the surface protection. This was followed by fogging the leg internals with Inhibitor C (powder) which is intended to settle into the stagnant water and provide inhibition at that level. Application of all three products for a single structure was done within the same day. The adoption of three different products followed the philosophy of incorporating multiple protective methods to mitigate the risk of corrosion.

Inhibitor A

Inhibitor A is a water-borne amine carboxylate corrosion inhibitor for internal use that provides protection against corrosion due to bio-growth. Having been immersed in treated seawater for two decades, the internal surfaces needed such a surface treatment to mitigate the risk of microbiologically induced corrosion. Inhibitor A provides both contact and vapor phase corrosion inhibition to multiple metal types. Inhibitor A has extensive lab and field history that validates its performance. Its adsorption and effectiveness has been verified using electrochemical impedance spectroscopy and cyclic polarization. Vapor diffusion capability was also studied at the Manufacturer to determine whether Inhibitor A can diffuse through 100 ft (30 m) of 1 in (2.50 cm) tubing with no air movement. Inhibitor A was introduced into one box, which was linked to another with the tubing (Figure 1). After 24 hours the inhibitor was detected in the second box using a VCI detection kit confirming diffusion was achieved. The quantity of inhibitor used in the caisson leg was calculated to cover the surface area of the internal diameter and provide sufficient vapor phase to saturate the volume of the leg.

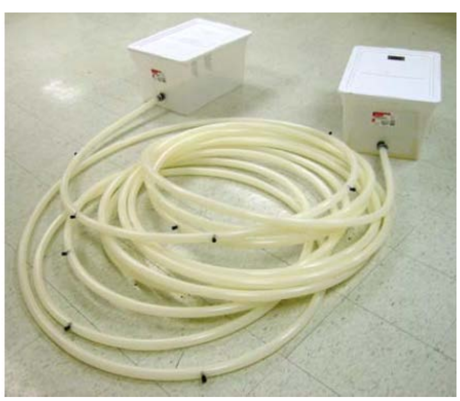

Figure 1: Testing apparatus for verifying VCI diffusion with no air movement

The original intention was to apply Inhibitor A using a three lance spray system. However, prior to adoption of this system, the Painting Section conducted a trial using their pipe coating system hung in the center of the leg. The pipe coater (Figure 1) was hung using a single sheave pulley attached to the scaffolding. The trial was successful and this application methodology was adopted. The application was carried out in one run starting from the bottom section going up. The pipe coater was raised slowly as it applied a pre-calculated quantity of product to ensure the entire uncoated surface was well covered. It took approximately 15 minutes to apply all the materials.

Figure 2: Application of Inhibitor A using a pipe coater

Inhibitor B

Inhibitor B is an amine carboxylate in powder form packed in lightweight breathable pouches that allow the diffusion of the VCI while maintaining the powder in a contained area. The pouch material is made of high-density polyethylene fibers manufactured in a flash-spinning process without the use of binders. This provides a durable rugged sheet structure that maintains properties even in the harshest environmental conditions. The contained inhibitor is suitable for ferrous metals only. Extensive testing had been done primarily using the Vapor Inhibiting Ability (VIA) test method.[5]
Inhibitor B is 100% biodegradable in marine environments and it is classified as a rapidly degradable substance (OECD[6] 306, BOD 28 Marine Test) as per testing performed in accordance with Oslo-Paris Commission Protocol. It has very low toxicity and has no bioaccumulation potential. The quantity of inhibitor used was calculated to saturate the volume of the leg.
Cross-angle bars were fabricated and bolted to the welded pad eyes inside the caisson legs (Figure 2). Inhibitor B pouches were attached through their button holes to a 6mm Stainless steel wire rope, which was then lowered down the leg. Three sets of pouches on wire were suspended. The first set of pouches accidentally detached when the buttonholes failed to hold the pouches. The other two sets were suspended successfully.

[6] Organization for Economic Co-operation and Development, 2, rue Andre Pascal, 75775 Paris Cedex 16, France

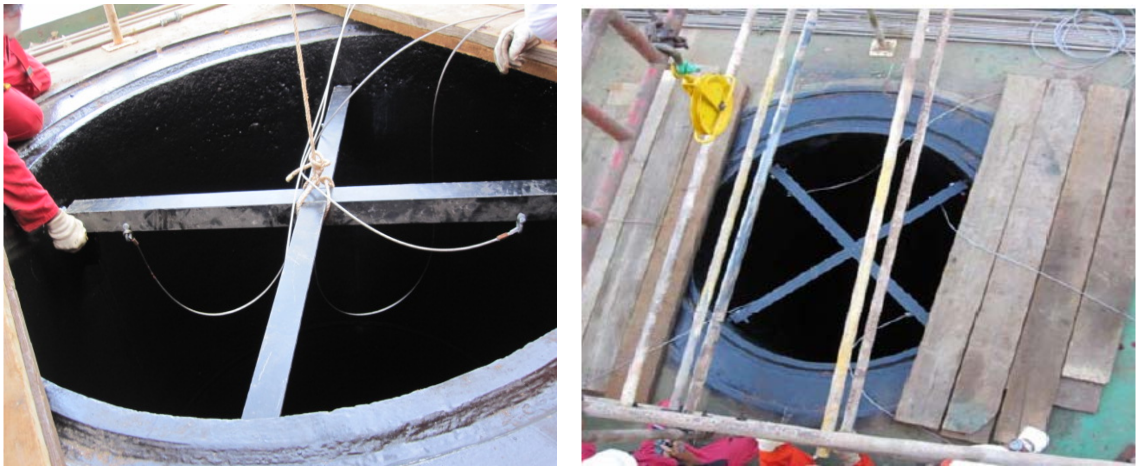

Figure 3: Steel frame setup for suspending Inhibitor B pouches.

Figure 4: Application of Inhibitor C by Fogging

Inhibitor C

Prior to the application, the painting section tagged the caisson leg and found a dead volume of water at the bottom. So it was decided to fog inhibitor C Powder in the caisson leg to allow it to settle into that water and provide protection in that critical zone. Inhibitor C is the same powder as Inhibitor B but supplied in loose powder form mixed with silica. The addition of silica improves the free flow properties of the powder through the application equipment.

An air compressor and an after-cooler were used to supply air to the blast pot. Since moisture is detrimental to this operation, all water traps were kept open. The material was loaded in a medium size blasting pot connected with 1 in (25.4 mm) diameter blast hose and the nozzle was removed to allow better flow. Application started with fogging the powder in the bottom of the caisson leg.

The caisson leg was then covered with a 15 mm steel plate (Figure 4) with an opening for carbon steel weight loss corrosion coupons attached to a small plate cover using a wire rope. Corrosion coupons were introduced to monitor and evaluate the effectiveness of the protection system.

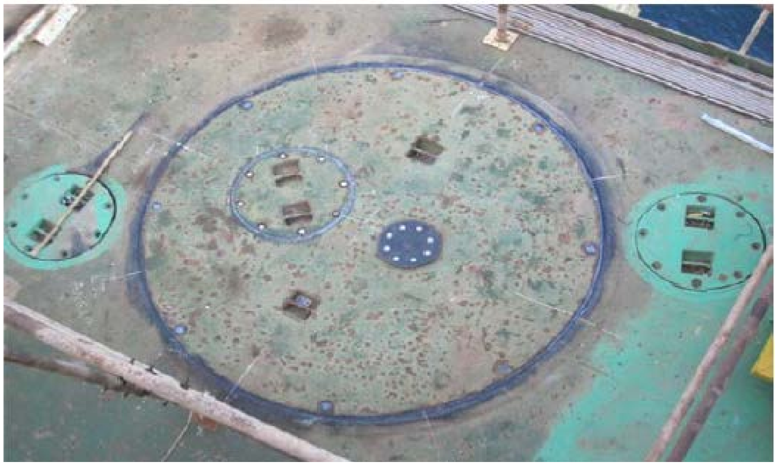

Figure 5: Caisson Leg Sealed Cover

RESULTS AND DISCUSSION

The corrosion coupons were retrieved and evaluated at different intervals (Table 1). The first such evaluation was in October 2011, one year after the pilot, when corrosion rate of 0.29 mils per year (mpy) was recorded. In January of 2012, the coupons were again evaluated as per ASTM G4-01[6] and found to have corroded at a rate of 0.11 mpy.

Figure 6: Weight Loss Corrosion Coupons

Since there was no control against which these results can be benchmarked, similar corrosion coupons were introduced in December 2010 in two control caisson legs that had not been emptied. Being full of water, one coupon was immersed in the treated water while another was installed in the overhead above the water line.

By September 2012, corrosion rate for the pilot leg was 0.45 mpy while the control leg corroded at an average of 12.90 mpy above the water line and 0.97 mpy under the water line.

In March 2013, the corrosion rate for the pilot leg increased to 3.18 mpy while the control leg corroded at an average of 16.50 mpy above the water line and 1.17 mpy under the water line.

The results showed clear improvement in the VCI-treated caisson leg where corrosion rates were maintained at low rates that were deemed acceptable. The methodology was adopted for the treatment of all other caisson legs at the complex.

In August 2013 another pilot was launched to qualify a new methodology for treated water disposal. After adopting this methodology, all caisson legs will be emptied and preserved.

Table 1
Corrosion Rates in Pilot and Control Caisson Legs

Caisson Leg		**Monitoring Location**	**Corrosion Rate, MPY**				
USEAP			**Oct.11**	**Jan.1 2**	**Sep.12**	**Mar.13**	**Sep. 13**
4494-0034	PC-USEAP-4494 0034	Above Water			12.63	18.56	11.88
4494-0034	PC-USEAP-4494 0034	Below Water			0.88	0.29	0.36
4494-0036	SB-USEAP-4494 0036	Above Water			13.23	14.44	10.98
4494-0036	SB-USEAP-4494 0036	Below Water			1.05	2.05	0.40
USAAP							
4494-0052	SB-USAAAP-4494 0052	VCI, pilot leg	0.29	0.11	0.45	3.18	0.09

ACKNOWLEDGEMENTS

The authors would like to thank ADMA-OPCO management for their support to this pilot project, and the team at Kanoo Group for their field support.

REFERENCES

1. S.Z. Levin, Volatile Inhibitors of Metal Corrosion, Second European Symposium on Corrosion Inhibitors (Ferrari, Italy, 1966), p.765.
2. V.S. Sartri, *Corrosion Inhibitors. Principles and Application,* 1st ed. (Hoboken, NJ, USA, Wiley & Sons Ltd, 1998): p.787 -789.
3. E. McCafferty, *Introduction to Corrosion Science*, 1st ed. (Berlin, Germany, Springer, 2010): 130
4. B. Bavarian, J. Zhang, L. Reiner, "Electrochemical and SCC Inhibition of Multi-alloy Systems using Vapor Corrosion Inhibitors", Corrosion 2013, paper number 2130, (Orlando, Florida, USA, NACE, 2013).
5. NACE TM 0208 (2008), "Laboratory Test to Evaluate the Vapor-Inhibiting Ability of Volatile Corrosion Inhibitor Materials for Temporary Protection of Ferrous Metal Surfaces" (Houston, TX: NACE International)
6. ASTM G4-01 (latest version) "Standard Guide for Conducting Corrosion Tests in Field Applications" (West Conshocken, Pennsylvania: USA ASTM International)