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VAPOR CORROSION INHIBITORS IN HYDRO-TESTING AND LONG TERM STORAGE APPLICATIONS

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ABSTRACT

Hydro-testing or hydrostatic testing of metallic equipment such as vessels, piping, valves etc. is an important method for quality control of parts, after production and during use. When water is used in these tests, corrosion of the metal, during and after testing is a concern. Vapor-phase corrosion inhibitors (VCI), when added to water in small concentrations are able to prevent corrosion during testing, during wet storage and after testing.

The mechanism of amino-carboxylate based vapor-phase corrosion inhibitors is to prevent corrosion of metals in three phases: within the solution, at the water line, and above the water line. VCI-based compounds prevent corrosion in the areas which are not reachable with other corrosion inhibitors. As authorized by the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) permit program controls water pollution by regulating point sources that discharge pollutants into waters of the United States. Generally NPDES permits exclude heavy metals, oils, and products outside of pH range 5-11. VCI makeup is in compliance with these requirements. Lab studies and examples of use on various pieces of industrial equipment will be presented in this paper to show effectiveness of VCI products in both fresh and salt water applications.

Key Words: Hydro-testing, corrosion, vapor-phase corrosion Inhibitors

INTRODUCTION

Hydrostatic testing is universally known and accepted as a means of demonstrating the fitness of a pressurized component for service.[1,2] These tests may take place on newly manufactured parts, or parts that have recently been repaired. Hydrostatic testing consists of raising the pressure level above the operating pressure to see whether or not any defects fail at pressures above the operating pressure.[1,2] If defects fail and are repaired or if no failure occurs because no such defect exists, a safe margin of pressure above the operating pressure is demonstrated.[1,2]

However, when metal is in contact with oxygen and water, corrosion will start and the process can be described with following equation:[3]

$$Me+n/2 \times H_2O + n/4 \times O_2 = Me(OH)n \qquad \text{(equation 1)}$$

Because majority of the systems subjected to hydro-testing are manufactured from carbon steel and cast iron, the focus of this paper is the corrosion protection of these metals.

Hydro-tests can be performed with waters of different chemistries including sea and brackish water, which are more corrosive to metals than fresh waters. Corrosion protection of the metal equipment during hydro-test and future storage can be acheved by using corrosion ihibitors and/or oxygen scavengers.

In some instances, equipment that has gone through a hydro-test will also be stored for future use or shipped long distances. This storage may take place while water is still inside the equipment (wet storage) or after draining.

Different classes of corrosion inhibitors may be used to protect systems from corrosion, including inorganic or organic. Inorganic inhibitors include nitrites, phosphorous based and others. Organic inhibitors are the products formulated from molecules constructed from C, H, O, or N atoms. Vapor-phase corrosion inhibitors (VCI) described in this paper are organic based blends. The mechanism of the corrosion protection of organic inhibitors includes the formation of a thin, some times monomolecular layer on the metal, which is a protective barrier to aggressive ions.[4] In the majority of cases, organic components form a physical bond with the metal substrate.

Formulations can include components with other functionalities for added protective capabilities. The main difference of the VCI products versus non VCI products, is the presence in the formulation of an ingredient with moderately high vapor pressure that can prevent corrosion in the vapor space without applying VCI directly to the metal surface.[4-6] The portion of this ingredient in the whole formulation will vary depending on the application. VCI adsorb on the metal surface and suppress metal dissolution and reduction reaction, in other words both: anodic and cathodic processes. The typical examples of this class are organic amines and their salts with carboxylic acids (amino-carboxylates). The advantage of VCI are that the volatilized molecules can reach hard-to-reach spaces. When they reach the metal, VCI attach to it by the active group.

The effectiveness of VCI also depends on their adsorption energy on the metal. It was found that amine types of the VCI are capable of forming a protective layer for up to three months, and as a rule, low molecular weight amines are more inclined to desorption than high molecular weight amines.

This paper presents the results of the evaluation of the effectiveness of VCI inhibitors when they are added to hydro-test water to prevent corrosion of metals during and after hydro-testing.

EXPERIMENTAL PROCEDURE

Several scenarios of the application of corrosion inhibitors during hydro-testing and wet storage were investigated. The first scenario is the addition of water soluble corrosion inhibitor to hydro-test water at concentrations sufficient to provide protection during hydro-testing and after water is drained. In this case, the residual film formed by the inhibitor on the metal should be effective enough to protect from corrosion during storage. This scenario is economically sound when the volume of hydro-test water is relatively small, or water can be reused for hydro-testing several times, because the concentration of corrosion inhibitor should be relatively high.

The second option is to use relatively low dose of the corrosion inhibitor, which will prevent corrosion only during the time when the water is inside the system, and then when water is drained, fog in a VCI product which is usually effective in a low dose (~0.5 kg per 1 m^3) and has the ability to spread its protective vapors.

The most challenging scenario is the situation when it is necessary to hydro-test large systems (X0000000 Liters volumes) and only water with high concentrations of chlorides and other aggressive salts is available. Such waters are very aggressive to metals and cause rapidly developing corrosion, including localized corrosion, such as pitting, crevice, etc. After draining water, residual salts will remain on metal wall. These salts may retain some water. In this case, the combination of a higher chloride concentration due to the partial evaporation of water and high concentration of oxygen make it very difficult for the corrosion inhibitor to provide a good level of protection.

The experimental effort was designed to show the effectiveness of several VCI Additives to prevent corrosion to various types of metals, such as carbon steel, galvanized steel, zinc, aluminum, copper, and brass under different application scenarios. Cast iron is very susceptible to corrosion but at the same time it is widely used by industry. Because of this, special attention was paid to the corrosion protection of systems made from cast iron.

The laboratory experiments consisted of immersion or partial immersion tests along with electrochemical tests, to represent conditions during hydro-test and wet storage. Tests were also set up to verify the effectiveness of film forming inhibitors during hydro-test, to verify the film would be sufficient for “after-action protection”, when the hydro-test water would be drained.

Experimental Materials

The choice of corrosion inhibitors for this study was made based on their functions during applications described above. VCI A, VCI B and VCI C are water soluble products; VCI A is a liquid, VCI B and C a dry powder. These three products were designed to work with hydro-tests using fresh water.

VCI A is a combination of film formers and vapor corrosion inhibitors. The main ingredients are salts of amines and organic acids of different chemical structure and triazole. The main function of this product is formation of a protective film with some vapor corrosion inhibition action.

VCI B is a vapor corrosion inhibitor based on ammonium salt of aromatic acid in the powder form. It is 100% biodegradable within 28 days.[7]

VCI C is a synergistic VCI blend of organic and non organic salts of carboxylic acids, triazole, and alkalinity builders. VCI C usually acts as a film-former/ passivator and capable to protect ferrous metals from corrosion even in the presence of relatively high concentrations of Chloride and Sulfate ions.

VCI D is a combination of biodegradable surface modifiers, chelating agents and oxygen scavenger. VCI D is a water soluble corrosion inhibitor for salt water.

VCI E is a vegetable oil based corrosion inhibitor. Because of its high surface activity VCI E if added to hydro-test water, attaches to the metal walls and protects them from corrosion. This product contains ~91% bio-based material and is applied as a float coat.

Metal panels for testing were made from Carbon Steel (SAE 1010), Cast Iron SAE G-3500, Class 35, Copper CA -110, Aluminum A-3105 H 24, Electro-galvanized Steel ASTM B-637, Grade SC-2. Panels were washed with Methanol and air dried before testing.

Local tap water with a TDS level of 350 ppm +- 20% and conductivity level of ~ 520 µS was used for the majority of testing. Artificial sea water was prepared using 'Instant Ocean' synthetic sea salt, and corroded pipes provided by customer were immersed in the solution; in all other cases when water of certain chemistry was designed for evaluation the de-ionized water and laboratory grade salts were used to prepare solutions.

It is a common practice to use biocides during hydro-testing. To address this situation compatibility of VCI inhibitors with oxidizing and non-oxidizing biocides were evaluated, such as Towerbrom, obtained from Stellar Manufacturing Co. and MEST-5 (2-Thicyanomethyl-thio benzothiozole), obtained from Buckman Laboratory.

Testing Program

Immersion And Partially-Immersion Corrosion Tests. Immersion tests were performed in conditions based on recommendations of ASTM G-31.[9] Sanded and cleaned with methanol metal panels were immersed and/or partially immersed in water-based solutions/electrolytes with or without treatment ('Control'). The effectiveness of the corrosion protection was evaluated using mainly two criteria: time before corrosion would start (visual evaluation) and weight loss compared to the control sample (no inhibitor).

In cases when weight loss was used as a criteria of the effectiveness of the corrosion inhibitors corrosion products were removed using the recommendations of ASTM G-1[10] and corrosion rate calculated according to ASTM G-31, Corrosion rate: (K x W)/(A x T x D) , (equation 2)

where $K = 3.45 \times 10^6$, T = exposure time in hours, A = area in cm^2, W = mass loss in g, D = density in g/cm^3 .

Protection Ability (%) was calculated using formula:

$$\text{Protection Ability} (\%) = \frac{\text{Corrosion Rate of Control - Corrosion Rate of Sample}}{\text{Corrosion Rate of Control}} \times 100 \qquad \text{(equation 3)}$$

Electrochemical Testing. Electrochemical tests were performed in conditions based on recommendations of ASTM G-5[8] using a Potentiostat/Galvanostat "Versastat" with three electrode system along with corrosion software model 352/252 SoftCorr™ utilized for the electrochemical studies. The working electrode (made of zinc, carbon steel, etc.) was polished with 600 grit sand paper, washed with methanol and air dried for at least half an hour at room temperature. Polarization curves were obtained at room temperature after the working electrode was immersed in the electrolyte for at least 30 minutes.

Test Procedure For "After Action" Evaluation. The purpose of the test was to find out how long the film built on the metal surface during hydro-test would protect from corrosion after water was drained. For the water based inhibitors "after-action" was evaluated as follows.

After immersion test was finished, ~98% of the test solution was drained and jars with panels inside were resealed. Panels inside the jars were visually checked for corrosion development at the regular basis.

Considering that "after action" of oil based VCI D is very effective, the test was more severe for this product. Panels were immersed in hydro-test water containing oil based VCI D, at room temperature overnight, and then removed from the jars and placed into a humidity cabinet set for testing according to ASTM D-1748 (Standard Test Method for Rust Protection by Metal Preservatives in the Humidity Cabinet [11] or in a Salt Spray Cabinet set according ASTM B-117[12]. Time before corrosion started was recorded.

Aquatic Toxicity Testing. The VCI Additives were tested for aquatic toxicity with several species. These tests included 48-hour static-renewal Daphnia pulex and Pimephales promelas definitive tests which were performed in synthetic moderately hard freshwater according to EPA/600/4-90/027F and 48-hour static-renewal acute M. beryllina and M. bahia definitive tests which were performed in synthetic seawater according to EPA-821-R-02-012. These tests found the No Observable Effect Concentration (NOEC), Lowest Observable Effect Concentration LOEC, and/or LC_{50}, the Lethal Concentration to 50% of the tested population.

LABORATORY TEST RESULTS

The results of the laboratory testing of the VCI additives are presented in the tables below. The data in Table 1 shows the performance of VCI A on carbon steel, copper and galvanized steel.

(8) ASTM International (ASTM), 100 Barr Harbor Dr., West Conshohocken, PA 19428

TABLE 1
VCI A: IMMERSION AND HALF - IMMERSION TEST RESULTS

Concentration of VCI A, % wt.	Metal	Time Before Corrosion Started	
		Immersion	Partially Immersion
0.3	Carbon Steel	> 7 days	> 7days
Control (no treatment)	Carbon Steel	< 1day	< 1 days
0.2	Copper	-	> 72 hours
Control (no treatment)	Copper	-	Slight corrosion after 72 hours
0.2	Galvanized Steel	-	> 72 hours
Control (no treatment)	Galvanized Steel	-	Slight corrosion after 72 hours

It is expected that oxidizing biocides would increase corrosion of metals; at the same time even non-oxidizing biocides can be incompatible with corrosion inhibitors. Table 2 presents the affect of biocides on the corrosion protection provided for carbon steel by VCI A.

TABLE 2
PERFORMANCE OF VCI A IN THE PRESENCE OF BIOCIDES

Concentration of VCI A, % wt.	Biocide, ppm	Presence of Corrosion After 14 Days of Testing	
		Immersion	Half-Immersion
0.3	MEST 5, 100ppm	No visible corrosion	No visible corrosion
	MEST 5, 100ppm	Corrosion	Corrosion
0.3	TowerBrom, 25 ppm	No visible corrosion	V/P Corrosion
0.4	TowerBrom, 25 ppm	No visible corrosion	No visible corrosion
Control (no VCI A)	TowerBrom 25 ppm	Corrosion	Corrosion

Addition of the properly chosen non-oxidizing biocide can have no affect on the corrosion protection provided by VCI A, at the same time oxidizing biocides accelerate corrosion especially in the vapor phase and the treatment level of the inhibitor should be higher to compensate for their corrosiveness.

As mentioned above, VCI B is mainly used for the protection in the vapor phase and is known for its ability to spread its vapors a distance from the source to difficult to reach places of the metal system, which should be protected from corrosion.[4-6] But besides this unique ability, it was also found that VCI B can very effective protect galvanized steel from corrosion. According to the immersion test in waters very aggressive to galvanic coating, with pH level of 11.6, VCI B protects the galvanized steel from corrosion when added at the rate of 0.5 %wt.

Immersion and partial immersion testing of carbon steel and cast iron in water containing VCI C were set up to study its effectiveness as a hydro-test additive. Results of 120+ hour tests can be seen in Table 3 below.

TABLE 3
VCI C IMMERSION AND PARTIAL IMMERSION TESTS ON CARBON STEEL AND CAST IRON

VCI C Treatment Level, % wt.	Metal	Half Immersion Test, Presence of Corrosion After 120 Hours	Immersion Test, Corrosion Rate/Presence After 120 Hours	
			Corrosion Rate, mpy	Protection Ability, %
0.15	Carbon Steel	No visible Corrosion	0.1181	93.22
0.2	Carbon Steel	No visible Corrosion	-	-
Control (No VCI C)	Carbon Steel	Corrosion	1.7416	-
1.0	Cast Iron	No visible Corrosion	-	
Control (No VCI C)	Cast Iron	Corrosion	-	

In very many cases, fresh water is not available for the hydro-testing and VCI products can also be used to prevent corrosion caused by waters with different levels of salinity including sea water.

The following example with results shown in Table 4, illustrates the effectiveness of VCI D, added at concentration of 0.8%wt to see water for corrosion protection of a pre-rusted metal. Electrochemical technique was used for this study because it is difficult to evaluate quantitatively effectiveness of the corrosion protection provided by the inhibitor on pre-corroded metal. Polarization curves in Tafel technique were obtained using the pre-rusted steel as a working electrode. Comprising of the corrosion rates with and without inhibitors shows that the addition of VCI D cut the corrosion rate on carbon steel in sea water by 50% versus the 'Control'.

TABLE 4
ELECTROCHEMICAL EVALUATION OF EFFECTIVENESS OF VCI D ON PRE-RUSTED CARBON STEEL PIPE IN ARTIFICIAL SEA WATER

Material	Corrosion Rate (mpy), determined from the Tafel plots	Weight Change in Immersion Test (g)*
0.8 %wt VCI D	0.6272	+0.04
Control (seawater)	1.2156	-0.81

Weight change was determined without removing corrosion products.

VCI E is the only non water based product tested for effectiveness of it corrosion protection during hydro-test and wet storage applications. It is especially effective, both by economic and protective standards for large salt water applications. The performance of this product in artificial sea water is presented in Table 5.

TABLE 5
EFFECTIVENESS OF VCI D IN ARTIFICIAL SEA WATER

Treatment	Time Before Corrosion Started, Days	% of Metal Surface Covered With Corrosion After 10 Days	Comments
VCI D 0.15 %wt	> 25 days	0	VCI D was added to jar, then metal panel was inserted and then sea water added.
Control (artificial sea water)	< 2 hours	100%	

In cases where a metal vessel needs to be tested it is recommended to first add VCI D. When water is added, VCI D floats up and covers all the metal surfaces.

"After action" of inhibitor is required to provide corrosion protection after hydro-test water would be drained. Laboratory study included tests, to investigate how long the protective film formed by the adsorption of VCI additive would be effective. The results of these tests are presented in Table 6.

TABLE 6
AFTER ACTION OF VCI

Treatment	Metal	Type of Hydro-test water	Conditions After Hydro-test Water Was Drained	Time Before Corrosion Developed
10 %wt VCI A	Cast Iron	Tap water	Sealed wet jar (>95%RH)	>16 month
5 %wt VCI C	Cast Iron	Tap water	Sealed wet jar (>95%RH)	>16 month
Control (no inhibitor)	Cast Iron	Tap water	Sealed wet jar (>95%RH)	< 2 hours
2 %wt VCI A	Carbon Steel	Well Water (TDS= 5000ppm, Cl^-=1000 ppm	Humidity cabinet, RH 80%, T 40 C	>2.5 hours
1 %wt VCI C	Carbon Steel	Well Water (TDS= 5000ppm, Cl^-=1000 ppm	Humidity cabinet, RH 80%, T 40 C	>2.5 hours
10 %wt VCI E	Cast Iron	Tap Water	Humidity cabinet, RH 80%, T 40 C	>1.5 hours
5 %wt VCI E	Cast Iron	Tap Water	Sealed wet jar (>95%RH, RH 80%, T 40 C	>1.5 hours
5 %wt VCI E	Carbon Steel	Artificial sea water	Sealed wet jar (>95%RH) Water was 10 times drained and refilled with/out	> 7 days

			addition of new portion of inhibitor	
5 %wt VCI E	Carbon Steel	Tap Water	Sealed wet jar (>95%RH)	1630 + hours
5 %wt VCI E	Carbon Steel	Tap Water	Humidity cabinet, ASTM D 1748 (>95% RH, 49 C)	800+ hours
5 %wt VCI E	Carbon Steel	Tap Water	Salt Spray Cabinet, ASTM B 117 (spray of 5%NaCl, 35 C)	450 hours

Based on the VCI testing presented above, guidelines for use of VCI products have been compiled into Table 7, which shows the recommended dose of each VCI additive during testing and when possible for “after action” protection up to 24 months.

TABLE 7
RECOMMENDED DOSE RATES OF VCI ADDITIVES

Fresh Water

Form	Product	Metals Protected	During Testing	1-3 Months	6-12 Months	12-24 Months
Water Soluble Liquid	VCI A	Multimetal	0.3-0.5%wt	0.5-1%wt	0.5-1%wt	0.6-1%wt
Water Soluble Powder	VCI B	Steel, aluminum, zinc	0.5-1%wt	1-1.5%wt	3-5%wt	5%wt

Cast Iron in Fresh Water

Form	Product	Metals Protected	During Testing	1-3 Months	6-12 Months	12-24 Months
Water Soluble Powder	VCI C	Cast Iron	0.75-2 %wt	5 %wt	5-7 %wt	7 %wt
Oil Float Coat	VCI E	Cast Iron	Dosage based on area to be protected: 1250 ft^2/gal (30.7m^2/L)			

Sea Water

Form	Product	Metals Protected	During Testing	1-3 Months	6-12 Months	12-24 Months
Water Soluble Liquid	VCI D	Multimetal	0.75-1 %wt	0.75-1 % wt	-	-
Oil Float Coat	VCI E	Multimetal	Dosage based on area to be protected: 1250 ft^2/gal (30.7m^2/L)			

Discharge of water used for hydro-test is an important part of procedure and it should be performed in a manner that does not harm the environment. Based on above, one of the very important questions to answer during the development of hydro-test scenario is how toxic is the treatment. The toxicity of VCI additives to several species was tested[13-20] and a summary of results is shown in Table 8 below.

TABLE 8
TOXICITY TESTING OF VCI

VCI A	VCI B	VCI C	VCI D	VCI E
48hr M. bahia (sea water) NOEC*=600ppm LEOC*=1000ppm	48hr M. bahia (sea water) NOEC=300ppm LOEC=600ppm		48hr M. bahia (sea water) NOEC=500ppm LOEC=1000ppm LC$_{50}$=1140ppm	48hr M. bahia (sea water) NOEC=3000ppm LOEC=5000ppm LC$_{50}$=3410ppm
48hr M. beryllina (sea water) NOEC=1000ppm LOEC=2500ppm	48hr M. beryllina (sea water) NOEC=150ppm LOEC=300ppm	48hr D.pulex NOEC=10,000ppm LOEC=>10,000ppm	48hr M. Beryllina (sea water) NOEC=6000ppm LOEC=12000ppm LC50=8316	48hr M. beryllina (sea water) NOEC=2160ppm LOEC=3600ppm LC$_{50}$=>10000ppm
48hr P. Promelas fathead minnow LC*$_{50}$=1659ppm IC*$_{25}$=141.2ppm	72hr Skeletonema costatum EC$_{50}$=240ppm EC$_{90}$=680ppm	48hr P. promelas NOEC=10,000ppm LOEC=>10,000ppm		48hr D.Magna NOEC=4000ppm LOEC=8000ppm LC$_{50}$=5464ppm
	10 day Corophium volutator LC$_{50}$= 1410mg/kg LC$_{90}$=2800mg/kg NOEC 1014mg/kg			48hr Rainbow Trout NOEC=1000ppm LOEC=1500ppm LC$_{50}$= 1498ppm
C. dubia (Water Flea) LC$_{50}$=1051ppm IC$_{25}$=86.7ppm	48hr Acartia tonsa LC$_{50}$ =100ppm LC$_{90}$= 220ppm NOEC=32ppm			72hr Selenastrum capricornutum NOEC=100ppm LOEC=250ppm IC$_{25}$=129.3ppm IC$_{50}$=180.3ppm

- NOEC – no observable effect concentration;
- LOEC – lowest observable effect concentration;
- LC$_{50}$, LC$_{90}$, LC$_{25}$- Concentration which kills 50, 90 and 25 % of population sample;
- EC$_{50}$, EC$_{90}$ – Concentration which affects 50 or 90 % of population sample.

Generally the acceptance criteria are based on local regulation, but the attitude is not to use chemicals which show NOEC lower than 10 ppm. The discharge should be performed in a way that water does not contain higher than designed concentration of the chemical. VCI additives (at recommended concentration for use) remain safe for many species, allowing discharge according to local specifications where minimal, if any, dilutions are necessary.

FIELD EXPERIENCE

Problem 1

Corrosion was developing on internal surfaces of pipelines and vessels. It was especially evident during and after hydro-testing. These pipelines and vessels were located on offshore platforms, refineries, and onshore oil & gas receiving stations.

Background. In 1995, the Norwegian Pollution Control Authority (SFT) implemented the (OSPAR) Harmonized Offshore Chemical Notification Format (HOCNF). Its primary function is to document and control the environmental properties of offshore chemicals. HOCNF documentation tracks chemical ingredients as well as toxicity, biodegradation and bioaccumulation testing data. SFT issues discharge permits. These permits enable the operating oil companies to change chemicals without additional permits provided that the environmental risks are not increased. These permits require the operator to gradually and systematically replace chemicals that have questionable environmental effects with less harmful products. All the operators are all held to the same strict discharge regulations. The use of traditional petroleum oil based products and other hazardous chemicals have been under severe scrutiny. Oil based products not only pose hazard to environment and the operators, but they also fail to perform well in applications such as hydro-testing. In addition, many of these products are difficult to use and add laborious removal procedures.

Solution. VCI have been used for offshore and onshore applications for many years. VCI B Powder provides a solution for hydro-testing applications. VCI B has extremely low toxicity levels, the LD-50 for rats is 2100 mg/kg (less than that of common table salt, which has a LD-50 of 2000 mg/kg for rats). VCI B was used during hydro-testing and for preservation of internal surfaces on pipes and vessels.

Application. Applications included large pipe systems on offshore platforms and smaller systems on refineries, onshore oil & gas receiving stations. VCI B powder is simply mixed into the hydro-test water according to the recommended dosage. After hydro-testing, the mixture of water and VCI powder is drained into a tank and used again or drained into the sea. The concentration used for this application is based on the amount of time needed for protection. It is normally between 1-3.5 %wt by weight of water.

Conclusion. There are numerous reasons why the customer likes to use VCI B. They include ease of storage, ease of application, environmental friendliness, and no need for expensive and messy removal before system startup. More and more, VCI B Powder is replacing traditional oil-based water emulsifiers.

Problem 2

The British Navy added two large voids, called blister tanks, to either side of the hull of a vessel. These were hastily added and incorrectly coated; within one year corrosion was evident beneath the surface.

Application. VCI B Biodegradable Powder was fogged into the void spaces. Metal probes were suspended along the void spaces for future inspection purposes and the area was sealed.

Conclusion. The British Navy was pleased to find that the corrosion stopped. A program of continuous monitoring using the metal corrosion probes was initiated. It is estimated the re-application of VCI B Biodegradable Powder will not be required for 2 years.

Problem 3

Customer needed to protect eight massive reaction chambers from corrosion prior to installation. The chambers were stored near the ocean during short term lay-up. Harsh environmental conditions included strong winds, dramatic changes in weather, heavy dust and highly corrosive air. The size of the chambers required an inhibitor that would be inexpensive and simple to use while offering effective protection from corrosion. Previously, the reaction chambers had been vacuum sealed with nitrogen.

Application. Customer chose VCI B powder, which is designed to protect metals in an enclosed space - ideal for the insides of the metal reaction chambers. The chambers are 5.5 yd (5 m) in diameter, 30.6-28.3 yd (2 -35 m) long, and divided into three internal sections. Technicians entered the reaction chamber through a huge top nut and spread VCI B powder inside, then sealed the opening with a thick plastic sheet. Metal corrosion probes were installed in a branch pipe to monitor the VCI protection. Data was collected weekly for quality assurance.

Conclusion. VCI B was effective and was chosen because of its worldwide track record of corrosion protection, ease of implementation, and affordable cost of entire operation.

Problem 4

Customer manufactures metering skids to measure the volume of oil or gas coming from offshore fields. Pipe-work on the skids is hydro-tested with water after mounting. The skids are then sent to their final destination where they can be stored for many months before operation. This equipment has strict requirements for cleanliness and no internal corrosion is accepted.

Solution and Application. Metering stations are hydro-tested with a 500-ppm aqueous solution of VCI A. After the hydraulic test, the solution is sent back to a storage tank for future use. VCI B is then fogged inside the openings at a ratio of 500 grams per cubic meter. Finally, the openings are capped to seal the installation. The VCI B is either left in place with no detrimental effect to the operations or simply flushed with water, and subsequently disposed of in the sea.

Conclusion. VCI A and VCI B demonstrated superior performance and were chosen for the following reasons: ease of implementation, effectiveness, and environmentally friendly products.

Problem 5

The subcontractor needed to perform hydrostatic testing on the tanks that were fabricated for the customer. The project involved the hydrostatic testing of 11 vessels with capacities varying from 10,382 cubic meters (2.7 million gallons) to 45,156 cubic meters (11.9 million gallons). The subcontractor had to provide an economical and environmentally acceptable method of corrosion protection for interior carbon steel surfaces during hydrostatic testing. Due to the scarcity of potable water in the United Arab Emirates, it was decided to use seawater for performing the hydrostatic testing. VCI E and oxygen scavenger were selected for this application.

Application. Prior to the application, all foreign materials were removed from the tanks. VCI E Float Coating at the concentration of 6 m^2 (per liter) and oxygen scavenger at 100 ppm were added to a tank and then the required volume of seawater was pumped in for the hydrostatic testing. The length of the hydrostatic tests of the different tanks varied from 35 to 45 days. The seawater was reused in several tanks. For the hydrostatic test of the next tank in line, the full calculated amount of VCI E and a reduced amount of oxygen scavenger were added. After hydrostatic testing, the interior surfaces of the tanks were immediately cleaned to remove any residual chloride prior to application of an epoxy coating.

Conclusion. This chemical system provided the most economical and environmentally acceptable method of effective corrosion protection for interiors of carbon steel tanks subjected to hydrostatic testing using seawater. The customer did not need additional biocide which would have been both costly and environmentally undesirable. The treated seawater, after hydro-testing, meets all requirements for discharge back to the sea. In addition to providing a high level of corrosion protection, this technology also offers environmental benefits, including biodegradability and the ability to lower bacterial count in treated seawater.

CONCLUSIONS

1. According to the results of laboratory tests studies and case histories above, VCI additives can be added to water to prevent corrosion of various metals during hydro-testing and after. When necessary, other VCI products can compliment hydro-test additives for long term storage.

2. Effectiveness of VCI products is confirmed in various water chemistries including fresh and salt water.

3. VCI solutions can be reused for several tests to save time and money. Additional advantage is that VCI used in hydro-testing also protect metal after water is drained, giving "after action" protection during storage and/or shipping.

4. According to the test results VCI additives have low toxicity level and waters containing VCI remain safe for many species, allowing discharge according to local specifications.

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