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Design Of A Cathodic Protection System For 2,000 Barrels Crude Oil Surge Tank Using Zinc Anode

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Abstract—This Paper details the Design of a Cathodic Protection System for the internal face bottom plate and shell course plates of a 2,000 Barrels (BBLs) Crude Oil Surge Tank for a Flowstation in the Niger-Delta region of Nigeria. Test for Ground Resistivity were carried out and the Results were used to determine that a zinc sacrificial anode Cathodic Protection System was sufficient for the protection. Sizing for the anodes was also done. The design was done in accordance to API Recommended Practice 651 – Cathodic Protection of Aboveground Petroleum Storage Tanks

Keywords—Cathodic Protection; Tank; Sacrificial Anode.

I. INTRODUCTION

Corrosion is defined as the chemical or electrochemical reaction between a material, usually a metal or alloy, and its environment that produces a deterioration of the material and its properties. In order words it is the passage of metals into the chemically combined state. According to the characteristics of the environment, corrosion processes are classified as chemical or electrochemical. Corrosion is a costly worldwide problem. In addition to the huge cost in economic terms, corrosion is also blamed for many of the disasters that cause loss of life and devastating pollution to the environment. (1)

Corrosion is a natural phenomenon and proceeds by well understood laws, hence can be prevented and controlled. Four conditions have to be present before corrosion can occur, namely

1. A metal capable of undergoing an anodic reaction-all metals can
2. An environment containing a corrodant or cathodic reactant capable of oxidizing the metal to a chemically combined state- not all environments can
3. An environment that is electrolytically conducting
4. A metal/environment interface that allows the transfer of electrical charges. (2)

Corrosion is a process and not a property of any metal, hence the rate cannot be easily calculated as it depends on a complex interaction between material, environment and the circumstance of exposure.

Different principles can be used to prevent corrosion which include the following:

- Appropriate materials selection.
- Change of environment.
- Suitable design application of coatings.
- Electrochemical i.e. cathodic and anodic protection,
- Appropriate Design

The choice between these possibilities is usually based upon economic considerations, but in many cases other factors such as appearance, environment and safety must also be taken into consideration. Two or more of the principles are commonly used at the same time (3)

The mitigation of corrosion for crude oil storage tanks is required for protection from failure of the storage tanks. Cathodic protection is one of the effective ways of reducing the rates of corrosion. A tank would corrode internally and externally. Protecting the bottom plates, annular plates, shell courses and roof plates from corroding is extensive but essential for good practice and cost savings.

Corrosion Allowance and Coating can reduce the effects of external corrosion to a large Degree in above ground tanks. This is also true for the internal course shells of a tank exposed mainly to Crude Oil. But the bottom plate which is exposed to retention water is exposed to a more corrosive environment

Experience has revealed that corrosion may occur on the inside surface of a tank bottom. The extent or nature of corrosion depends on many factors associated with the composition of the fluid in contact with the steel bottom. The factors include Conductivity (a function of dissolved solids), Suspended solids, pH level, and dissolved gases such as C02, H2S, or 02. (4)

An effective way of mitigating this internal bottom plate corrosion is by Cathodic Protection. Cathodic protection (CP) is a technique used to control the corrosion of a metal by making it the cathode of an electrochemical cell. The simplest method to apply CP is by connecting the metal to be protected with another more easily corroded metal to act as the anode of the electrochemical cell. (5)

This Paper aims to detail the design of a cathodic protection system using zinc anode in an oil and gas land facility

II. Mechanism of Cathodic Protection

Every metal has a tendency to revert back to its chemically combined state after it is extracted from its ore. This usually happens under the action of oxygen and water. This is called corrosion, the most common example is the rusting of steel. (6)

Corrosion is an electro-chemical process that involves the passage of electrical currents on a micro or macro scale. The change from the metal to its original state occurs by oxidation of the metal that is the losing of ions of the metal. It is also called the anodic reaction. Below is an example of an anodic reaction that occurs in steel (2)

$2Fe \rightarrow 2Fe^{2+} + 4e^-$

This reaction produces free electrons which pass within the metal to another site called the cathode on the surface of the metal. The reaction at this site is called the cathodic reaction, and here oxygen in the environment is reduced hence it is also called a reduction reaction. (2)

$2H_2O + O_2 + 4e^- \rightarrow 4OH^-$

The reduction reaction in an acidic solution is quite different from that above, which is a neutral case, the equation is shown below

$4H^+ + 4e^- \rightarrow 2H_2$

Corrosion thus occurs at the anode but not at the cathode (unless the metal of the cathode is attacked by alkali).

The two equations that complete the process are electrochemical because they involve the release and consumption of electrons. The combination of the equations above yields the chemical reaction equilibrium. (2)

It follows that:

Aqueous corrosion of any metal will be by a chemical reaction and there will be chemical methods to control and monitor corrosion. Also it occurs by an electrochemical mechanism, this implies that there will be electrochemical methods of control and monitoring.

The sites where the anodic reactions occur are called anodes. The sites where the cathodic reactions occur are called cathodes. The rate of these electrochemical reaction may be controlled

Chemically by removing oxygen

Electrically by adding or removing electrons

Adding electrons to the system will reduce the electron released by the metal as it has to compensate for the extra electrons in the system, therefore the anodic reaction rate decreases and corrosion slows or ceases, and the addition of electrons to the system to stop corrosion from occurring is cathodic protection. (2)

III. Types of Cathodic Protection

Cathodic protection can be achieved in two ways:

1. By the use of galvanic (sacrificial) anodes, or
2. By “impressed” current.

A. Galvanic Anodes

Galvanic anode system is an intentional creation of an electrochemical cell where two dissimilar metals are connected electrically in order to protect one of them, this is achieved due to the difference in potential of the two metals. The difference in natural potentials between the anode and the metal, as indicated by their relative positions in the electro-chemical series, causes a positive current to flow in the electrolyte, from the anode to the metal. Thus, the whole surface of the metal (steel as a case study) becomes more negatively charged and becomes the cathode. The metals commonly used, as sacrificial anodes are aluminium, zinc and magnesium. These metals are alloyed to improve the long-term performance and dissolution characteristics. (7)

Cathodic protection in the sacrificial anode system is essentially a controlled electrochemical cell. Corrosion on the protected structure is shifted to the anode. The anode is consumed in the process but is designed and installed so that it is easily replaced when consumed. Anode life of 10 to 15 years is common. Anode life is dependent upon the amount of current emitted by the anodes and their size. (8)

Magnesium has the most negative electropotential of the three and is more suitable for areas where the electrolyte (soil or water) resistivity is higher. This is usually on-shore pipelines and other buried structures, although it is also used on boats in fresh water and in water heaters. In some cases, the negative potential of magnesium can be a disadvantage: if the potential of the protected metal becomes too negative, hydrogen ions may be evolved on the cathode surface leading to hydrogen embrittlement or to disbonding of the coating. Where this is a possibility, zinc anodes may be used. (9)

Zinc and Aluminium are generally used in salt water, where the resistivity is generally lower. Typical uses are for the hulls of ships and boats, offshore pipelines and production platforms, in salt-water-cooled marine engines, on small boat propellers and rudders, and for the internal surface of storage tanks.

Zinc is considered a reliable material, but is not suitable for use at higher temperatures, as it tends to passivate (becomes less negative); if this happens, current may cease to flow and the anode stops working. Zinc has a relatively low driving voltage, which means in higher-resistivity soils or water it may not be able to provide sufficient current. However, in some circumstances — where there is a risk of

hydrogen embrittlement for example — this lower voltage is advantageous, as overprotection is avoided.
Aluminium anodes have several advantages, such as a lighter weight, and much higher capacity than zinc. However, their electrochemical behaviour is not considered as reliable as zinc, and greater care must be taken on how they are used. Aluminium anodes will passivate where chloride concentration is below 1,446 parts per million.
One disadvantage of Aluminium is that if it strikes a rusty surface, a large thermite spark may be generated, therefore its use is restricted in tanks where there may be explosive atmospheres and there is a risk of the anode falling.
Since the operation of a galvanic anode relies on the difference in electropotential between the anode and the cathode, practically any metal can be used to protect some other, providing there is a sufficient difference in potential. For example, iron anodes can be used to protect copper (9)

1) Advantages of Galvanic Anodes

- Simple to install.
- Independent of any source of electric power (self-powered).
- Low maintenance requirement.
- Less likely to cause stray current interference problem on neighbouring structures.
- When the current requirement is small, a galvanic system is more economical than impressed current system. (10)

2) Disadvantages of Galvanic Anodes

- Low driving voltage.
- Limited to use in low resistivity soils.
- Not an economical source of large amounts of cathodic protection current. (10)

B. Impressed Current

Impressed-current systems employ inert (zero or low dissolution) anodes and use an external source of dc power (rectified ac) to impress a current from an external anode onto the cathode surface.
The connections are similar for the application of cathodic protection to metallic storage tanks, jetties, offshore structures and reinforced concrete structures.
Two types of Anodes mostly used;

1. Consumable anodes: provide current through the dissolution of anode material; usually anodes are scrap iron or steel.
2. Non consumable anodes: decomposition of the environment gives anodic current, anode reaction products (hydrogen ions and chloride ions) (2)

IV. DESIGN OF A CP SYSTEM USING ZINC ANODE

A. Technical Specifications

The specifications for the tank and soil used for the CP System design are given below;

1) 2,000bbls Surge Tank Specification

The Surge tank in a Niger-Delta flowstation to be protected by a Cathodic Protection System have the following specification.

TABLE I.

Equipment	Diameter	Height
Storage Tank	9.144m	5.486 m

Table 1 - Tanks Specification

2) Ground Resistivity

This design uses soil resistivity report done for a location in the same field. According to the report, the range of resistivity is between 100 Ω-m to 2100 Ω-m. (11) Using the lower range of 100, we can design for a moderately corrosive soil as given by National Association of Corrosion Engineers (NACE) Corrosion Basics

TABLE II.

Soil Resistivity(Ωcm)	Corrosive Level
0 - 500	Very Corrosive
500 – 1000	Corrosive
1000 – 2000	Moderately Corrosive
2000 – 10000	Medium Corrosive
P > 10000	Negligible

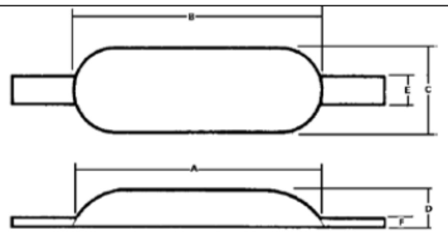
Table 2 - NACE Corrosion Basics (4)

B. Parameters

Design Life:	10 years
Tank Diameter (D):	9.144m
Tank Height (h):	5.486m
Coating quality:	100%
Desired Current Density:	2mA/m^2
Resistivity (r)	1000 ohm-cm
Zn Anode weight (for one anode) W_{an}	11.8 kg
Zn Anode current efficiency	95%
Current capacity of anode Ic	11.200 kg/A. year

C. Anode Specification

From SPA (An anode manufacturer's catalogue) specification for Zicoline shown below, WZ12 was selected

Shape	Order code	Type	A	B	C	D	E	F	G	Nett Wt.	Gross* Wt.
	805-80450	WZ4	355	255	75	32	32	3		3.3	3.6
	805-80460	WZ5(□)	230	150	150	25	25	5		3.6	4.0
	805-80475	WZ7	350	270	150	32	40	5		6.5	7.1
	805-80505	WZ12	533	406	150	32	40	5		11.1	11.8
	805-80520	WZ18	778	585	120	35	40	5		17.0	18.3
		WZ22	648	546	127	50	40	5		21.3	22.5
	805-80545	WZ27	648	546	127	64	40	5		25.9	27.0
	805-80550	WZ35	1016	914	127	50	40			35.0	36.5

D. Calculations

Tank bottom area $A_b = \pi \times r^2$

r = D/2 = 4.572 m

$A_b = \pi \times r^2$

= 3.14 x (4.572)²

=63.699 m²

Tank shell area $A_s = 2 \times \pi \times r \times h$

Tank height =5.486m

A_s =2 x 3.142 x 4.572 x 5.486

A_s =157.627 m²

Total area $A_t = A_b + A_s$

=63.699+157.627

=223.326m²

Total current required $I_t = A_t \times I_d$ (8)

Design current density " I_d " = 20 mA/m^2

=223.326 x 0 .02

= 4.47 Amp

Weight of Anode W= (t_f x I_t x I_c) / (I_e x 0.85) (8)

Where,

t_f – Design life=10 year

I_t – Total Current Required = 4.47Amp

I_c – Current capacity of anode = 11.200 kg/A. year

I_e – Zn Anode current efficiency= 95%

Utilization factor= 85%

W = (10 x 4.47 x 11.2) / (0.95 x 0.85)

= 619.99 Kg

Required anode quantity (12)

N = Weight of Total required anode / weight of one anode

N = 619.99 / 11.2

N = 55.4

N= 56

Current Output per Anode = 4.47/56

= 0.08 Amp

Area to be protected by one anode

An= At / N = 223.326m² / 56

An= 3.99 m²

V. Conclusion

The design of a Cathodic Protection System using Zinc Anode for a 2,000 Barrels tank requires 56 Zinc (WZ12) anodes. This proves to be a simple and convenient solution to corrosion issues and should be further explored in above ground Crude Oil Storage and Petroleum storage tanks.

VI. References

1. Yang, L. 'Techniques for corrosion monitoring'', ,. Houston : Woodhead Publishing,, 2008.
2. Onyekpe, Basil. Corrosion in Oil and Gas Production. Ist. Benin : Ambik Press, 2002.
3. Robert, G. K., John, R. S., David, W. S., (Rudolph, G. B. Electrochemical Techniques in Corrosion Science and Engineering. Houston : Marcel Dekker, Inc, 2002.
4. API Recommended Practice 651. Cathodic Protection of Aboveground Petroleum. 2nd. s.l. : API, 1997.
5. Edward, G., R. Winston. 'Corrosion Resistance of Aluminum and Magnesium Alloys Understanding, Performance, and Testing. 2010.
6. Uhlig, H H. Corrosion and corrosion control. , . 3rd . New York : Wiley, 1985.
7. Bianchetti, R. Peabody's Control of Pipeline Corrosion. 2nd . Houston : s.n., 2000.
8. UFC. Cathodic Protection. [Online] 2016. [Cited: March 10, 2017.] http://www.wbdg.org/FFC/DOD/UFC/ufc_3_570_01_2016.pdf.
9. Wikepedia. [Online] 2016. [Cited: December 10, 2016.] https://en.wikipedia.org/wiki/Galvanic_anode.
10. Delano, P., Wegener D. Cathodic Protection. 2004.
11. Flowlines Nigeria Limited. Oredo Field Soil Electrical Resisitvity Investigation for 2 NOS Crude Oil Storage Tank. Benin City : s.n., 2011.
12. Katradis. [Online] 2015. [Cited: March 10, 2017.] http://katradis.com/anodes/calculations.
13. Recommended Practice. DNV-RP-B401 - Cathodic Protection Design. s.l. : DNV, 2010.
14. Morgan, J.H. Cathodic Protection' National Association of Corrosion Engineers (NACE). 2nd. 1987.

VII. List of Tables