INSTANTANEOUS ON/OFF POTENTIAL MEASUREMENTS AS A TECHNIQUE TO EVALUATE THE EFFECTIVENESS OF INTERNAL CORROSION CONTROL OF COATED CARBON STEEL WATER STORAGE TANKS WITH ICCP AFFORDED

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Abstract: In freshwater tanks, corrosion activity on internal wetted surfaces usually results in concentrated pitting attack, which leads to quicker wall penetration than if the corrosion was more uniformly distributed on the metal surface. This is particularly true on tank interiors that are coated, where the corrosion attack is accelerated at holidays or voids in the coating. The attack is initiated by the development of anodic and cathodic areas on the submerged metal surfaces. The anodic areas (e.g., location of coating holiday) will suffer accelerated corrosion (metal loss), whereas the cathodic areas will not corrode. The corrosion is often made even worse by the small anode-large cathode area effect. There are a number of mechanisms that can initiate and sustain corrosion of the submerged steel in water tanks. As a second corrosion barrier, and above all to avoid the problems described as a result of the application of the coating as a first barrier, the elevated water tank in question has afforded an impressed current cathodic protection system. There are two rectifiers. One for the bowl area and another for the riser area of the water tank.

Keywords: Immersed structure, IR free potential (EIR free) - Polarized potential criterion, Protection current (Ip), Permanent reference electrode, Impress Current Cathodic Protection. Coating Holiday (CH). “Native” potential measurements (nP).

1. INTODUCTION.

Corrosion is so common because most metals, such as carbon steel, are more stable as compounds than as pure metals. This is because they have a desire to move from a high energy "unstable" state to a lower energy "stable" state. A metal structure immersed in water is cathodically protected when there is a negative polarized potential of at least 850 mV with respect to a copper/copper sulphate reference electrode in contact with the electrolyte [1]. This criterion is based on the fact that the current required to protect the internal parts of carbon steel tanks must be sufficient to keep the potential of the metal at least as electro-negative as the region of stability for the metal at a given pH. See Pourbaix diagram Figure No. 1[2].

The concept of ON/OFF potentials as a corrosion control technique is based on the principle that when the CP is turned off, the IR component in the potential measurements decays almost instantaneously, but the structure-water interface polarization decays slowly over hours/days depending on a number of factors. These factors are beyond the scope of this article.

Underprotection caused by low current output can result in corrosion deterioration of the tank walls and severe pitting in the coating. Unlikely, overprotection caused by excessive current output can result in coating delamination, blistering, and eventually complete coating failure. Therefore, proper potential control is a fundamental factor in preventing corrosion damage inside the tank, both in the steel and in the coating.

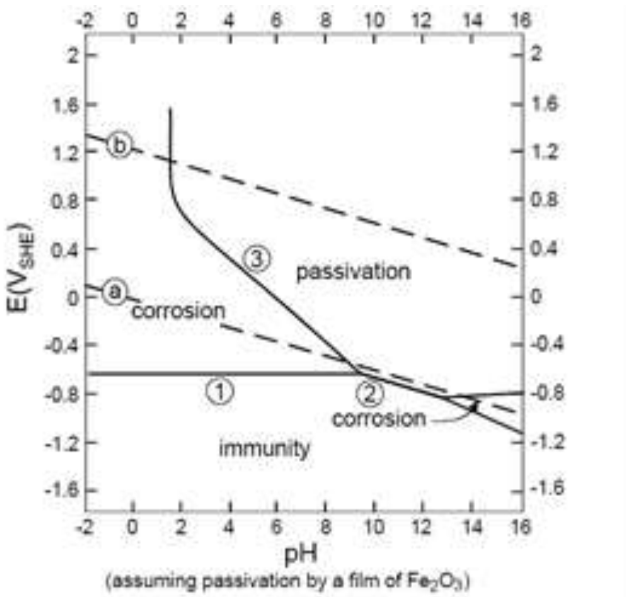

Figure 1. Pourbaix diagram (equilibrium E vs. pH) with the thermodynamic conditions of corrosion, immunity, and passivation of iron. [2]

2. EXPERIMENTAL PROCEDURE.

2.1. Epoxy Coated Welded Carbon Steel Structure to be protected.

The subject tank, constructed of carbon steel, is of the ellipsoidal elevated type with a basin 15 m in diameter and a wet riser 40 m in length. Since the steel tank is exposed to the stored water, it would be subject to corrosion. To mitigate this corrosion, coatings were applied to the internal surfaces at the time of construction. The coatings applied are based on a three-coat epoxy compound. The experimental procedure began after commissioning of the cathodic protection system described in this article. Potential readings and rectifier operating values were recorded periodically. Key observations are summarized in this article based on actual data collected from this elevated water tank, which is still in service today.

2.2. Rectifier Output.

The DC output levels of the rectifiers were recorded using a Fluke Model 87-V multimeter. To record the voltage, the meter was set to DC volts and the test leads were placed in contact with the rectifier output lugs. To record the current output, the meter was set to DC millivolts and high resolution. The meter clips were then connected across the rectifier panel shunts. The recorded DC voltage drop was multiplied by the shunt factor to calculate the current output. There are two rectifiers in use: One for the tank shell and one for the riser.

2.3. Installed Rectifier Capacities in our Case of Study.

Riser Rated Rectifier DC Output: 50 Volts 5 Amperes.
Bowl Rated Rectifier DC Output: 50 Volts 20 Amperes.

2.4. Anode Current.

For the bowl area of the elevated water tank, the Fluke meter was set to DC millivolts and high resolution. The meter clips were then placed over the shunt prongs in the test box. The value registered on the meter was divided by 10 to calculate the current in amperes. Twelve mixed metal oxide (MMO) anodes are suspended in the tank. Individual cables feeding the twelve anodes run in conduit to an anode bond box mounted between the rectifier units. Control circuits in the rectifier measure the voltage difference between the reference cells and the tank. The controllers then adjust the DC output of the rectifier to achieve the setpoint potential measurements. The setpoint potential is adjusted using the knob on the front panels of the rectifier.

For the riser area of the elevated water tank, the Fluke meter was set to DC millivolts and high resolution. The meter clips were then placed over the shunt prongs in the test box. The reading on the meter was multiplied by 5 and divided by 60 to calculate the current in amps. A string of 3mm diameter MMO anodes is suspended in the riser. The control circuits in the rectifier measure the voltage difference between the reference cells and the tank. The controllers then adjust the DC output of the rectifier to achieve the target potential measurements. The setpoint potential is adjusted using the knob on the rectifier front panels.

2.5. Potential Measurement.

Potential measurements were recorded using stationary and portable copper/copper sulfate reference cells. The Fluke meter was set to DC volts. For the permanent stationary cells, the voltmeter test leads were used to contact the cell and tank test leads in the rectifiers. The positive lead contacted the tank structure and the black lead contacted the reference cell. Synchronized current interrupters were used to record "instant off" potentials. When the rectifier is off, there is no DC current in the water and the cell potential is that of the protected steel. A current interrupter had been placed in the negative circuit of the riser rectifier, synchronized with another current interrupter in the negative circuit of the bowl rectifier. An interruption cycle of 20 seconds on and 2 seconds off was used.

3. RESULTS AND DISCUSSION.

3.1. Initial Tests as the Tank was filled with water.

Once the tank was in service, "native" potential measurements were recorded using stationary and portable reference cells in the bowl and riser. There are 4 stationary cells. Two in the bowl and two in the riser. In the bowl, they are located on the tank wall and on the bottom. See Figures 2 and 3. In the riser there are two more, one at the higher part and one at the bottom.

The portable cells were manually inserted from the manhole at the top of the tank (44 m high). They were lowered every 1 m and native potentials were recorded. Native potential measurements ranged from -559 to -695 mV and were indicative of freely corroding carbon steel. See tables 1 and 2.

After the native potential measurements were recorded, the rectifiers were energized. The AC input was checked and found to be 208 V. Each unit was then energized and the potential set points were adjusted. The set points were -1110 mV in the bowl and -1100 mV in the riser. Potential set points have been assigned to the reference cells at the end of the bowl (stub) and the bottom of the riser. The cathodic protection systems were then allowed to operate for one week before recording instant off potentials.

Table 1. Native potentials and On/Off potentials mV CSE. BOWL

	NATIVE	On Potential	Off Potential
1	- 690	-	-
2	- 690	-	-
3	- 690	- 1251	- 1050
4	- 689	- 1252	- 999
5	- 686	- 1251	- 949
6	- 686	- 1250	- 999
7	- 687	- 1243	- 1068

After this period of operation, the bowl rectifier unit operated at 1.45 V and 0.005 A, and the riser rectifier unit operated at 1.83 V and 0.035 A. Each of the anode circuits produced the desired current. The low current demand is a tribute to an excellent coating application. Synchronized circuit breakers were used in both rectifier units. "On" and "Instant Off" potential measurements were then recorded using the permanent and portable reference cells. To achieve effective corrosion control throughout the riser, an additional anode is required. The new anode was to be 15 m. along with 15 m. feet of #10 HMWPE pig tail.

Table 2. Native potentials and On/Off potentials mV CSE. RAISER

	NATIVE	On Potential	Off Potential
1	- 695	- 1225	- 1046
2	- 686	- 1211	- 1012
3	- 672	- 1182	- 890
4	- 658	- 1163	- 950
5	- 643	- 1142	- 926
6	- 641	- 1127	- 965
7	- 629	- 1119	- 917
8	- 619	- 1122	- 920
9	- 609	- 1129	- 922
10	- 600	- 1136	- 982
11	- 591	- 1143	- 882
12	- 584	- 1139	- 969
13	- 577	- 1143	- 943
14	- 572	- 1140	- 941
15	- 568	- 1130	- 824
16	- 565	- 1127	- 930
17	- 560	- 1123	- 823
18	- 559	- 1116	- 967
19	- 559	- 1130	- 841
20	- 559	- 1122	- 946
21	- 560	- 1122	- 880
22	- 561	- 1125	- 921
23	- 562	- 1124	- 925
24	- 566	- 1123	- 976
25	- 566	- 1125	- 910
26	- 565	- 1134	- 930
27	- 564	- 1126	- 919
28	- 571	- 1117	- 950
29	- 563	- 1100	- 820
30	- 563	- 1093	- 762
31	- 562	- 1073	- 737
32	- 560	- 1050	- 855
33	- 563	- 1005	- 780
34	- 563	- 937	- 797
35	- 563	- 823	- 750
36	- 563	- 715	- 626

Instant-off potential measurements within the bowl ranged from -949 to -1068 mV. All test points within the bowl met NACE criteria for effective corrosion control [1]. See Table 1.

Instant Off potential readings within the riser ranged from -626 to -1046 mV. Below a depth of 27 m, near the bottom of the riser, the protection levels drop off. This indicates that the original anode assemblies within the riser are too short. The anode material should be 3mm mixed metal oxide with an anchor weight. The anode would be spliced to the existing riser anode in the splice box on the tank roof. See Table 2.

3.2. Test during the maintenance and operation period.

One of the bowl reference cells, the one in the lower area #4 (stub), appears to be damaged or sensitive to a coating defect. See Figure 2.

Table 3. Rectifier readings in October 2021. Two years after tank commissioning. Current/volt outputs and on/off potential readings. Setpoint -1100 mV CSE

BOWL	
1,57 V	0,077 A
Cell at stub	-1073 / -675 mV
Cell at wall	-1501 / -1109 mV

Table 4. Rectifier readings from Feb 2024. Current/volt outputs and on/off potential readings. Setpoint -1100 mV CSE

BOWL	
1,60 V	0,033 A
Cell at stub	-950 / -622 mV
Cell at wall	-------

Figure 2. Permanent reference cell #4 (stub) of the bowl area inside the elevated water tank prior to commissioning.

Figure 3. Permanent reference cell #3 near the wall of the bowl area inside the elevated water tank prior to commissioning.

The cell #3 near the bowl wall, sometimes works and sometimes does not. See the figure 3. The reason why this cell does not work may be because the water level in the tank is not high enough to submerge the reference cell. If the reference cell is not submerged in the water, the potential cannot be read. The times when this cell shows a consistent reading is when the tank rectifier is providing a current greater than 70 mA. See tables 3 and 4. The more metallic structure is protected, the more cathodic protecting current is delivered.

Table 5. Rectifier readings of October 2021. Current/Volt outputs and on/off potential readings. Set point -1100 mV CSE

RISER	
1,72 V	0,243 A
Cell at bottom	-1080 / -725 mV
Cell at top of riser	-1500 / -1038 mV

Table 6. Rectifier readings of Feb 2024. Current/Volt outputs and on/off potential readings. Set point -1100 mV CSE

RISER	
1,72 V	0,375 A
Cell at bottom	-1070 / -716 mV
Cell at top of riser	-1530 / -1094 mV

The rectifier systems are designed to adjust the current output to maintain the tank to water potential at a preset constant value required for effective corrosion control. The current output values recorded after initial start-up will increase as a function of time as shown in Tables 5 and 6. This is due to the degradation of the riser coating and therefore an increase in bare structure to be protected. The reference cell at the bottom is located at a depth of 30 m. It is observed that IR free potential does not still satisfy the criterion of at least 850 mV with respect to a copper/copper sulphate reference electrode in contact with the electrolyte, See tables 5 and 6. The implementation of the recommendation to provide an auxiliary anode would have increased the level of protection and thus met the NACE criteria. [1]

4. CONCLUSIONS.

For potable water storage tanks, impressed current cathodic protection is the most common method employed for corrosion control. With this type of system, current is delivered from a DC power supply connected to relatively inert electrodes or anodes. Current is forced to flow from the electrode, through the electrolyte, to the metal surface. The major advantage of this type of cathodic protection system is the ability to adjust the amperage of the CP for changing water chemistry within the water tank and modified surface conditions of the metallic structure being protected.

Tables 5 and 6 show inadequate protection at the bottom of the riser. To achieve effective corrosion protection at the bottom of the riser, it is again strongly recommended that an additional anode assembly be installed inside the riser that extends to the bottom. The addition of a new anode wire to the existing positive anode will allow meeting the NACE criteria [1].

The relationship between cathodic protection and coatings inside a potable water storage tank is symbiotic. While cathodic protection mitigates corrosion at pinholes, voids and holidays, the coating electrically insulates most of the tank interior, allowing the cathodic protection system to operate at a much lower voltage level. The current required for cathodic protection is significantly reduced when coatings are used. The coating system should be compatible with the cathodic protection system. [3]

It is observed that the output current of the riser rectifier has increased significantly over time. A greater increase in the protection current indicates a greater area to be protected. Therefore, to maintain the same level of protection, the metal surface area have had to be increased. Even the best protective coating systems cannot prevent corrosion indefinitely. However, when cathodic protection is afforded to a coated tank, the benefit to owners of combining the benefits of a protective coating with cathodic protection is significant, doubling or even tripling the life of the coating. As a result, tank owners see cathodic protection as a cost-effective way to protect their investment in their storage tanks and protective coating systems. [3]

The times when reference cell No.3 gives a consistent reading is when the tank rectifier is supplying a current greater than 70 mA. If this cell fails and the one at the bottom does not give us protection readings, we will not have any accuracy of the tank protection level.

Replacing reference cell #4 would indicate if there are cracks in the coating or if the reference cell is damaged. If the reading remains outside the NACE criteria, there would be a holiday in the coating. Re-introducing portable cells from the top of the tank and recording instant off readings every meter, as was done when the tank was commissioned years ago, would give a very rough assessment of the condition of the coating and the inside walls of the tank.

5. REFERENCES.

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