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The Sacrificial Anode Cathodic Protection System of Sirte End Reservoir

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Abstract—In this work, Mg and Zn anodes were used as a sacrificial anode cathodic protection to protect an inlet, by-pass and draw-down pipelines of Sirte end reservoir. The potential survey readings have demonstrated that there was a low voltage of some protection Mg-anodes that effected by the phenomenon of the reverse current in some ground beds. As a result of this decrease, there was a clear effect on the readings of the potential difference and the decay test, where the high potential value was observed during the instantaneous separation after comparing it with the potential during the operation. When the decay test was performed, an increase in the potential value was observed, contrary to what was expected. As for the rest of the ground beds that did not register reverse flow in the current value, the results of the decay test were satisfactory where the shift value was more than 100 mV in the negative direction. As for the pipelines that are protected by zinc electrodes, all the potential readings for the protection anode electrodes are high and at the required level and there is no current of the reverse. However, when the decay test is carried out the required shift level did not reach it.

Keywords— Cathodic protection, Sacrificial anode, Reservoir, Inlet pipeline, Draw-down pipeline, By-pass pipeline, Potential survey.

1 Introduction

As part of phase one of GMMR (Great Man-Made River) project, Sirte end reservoir has a storage capacity of 6.8 million cubic meters of water that comes from Sarir town (south-east of Libya) via the Ajdabiya reservoir. The GMMR project is a water supply project constructed to extract and convey high quality ground water from deep aquifers in the Sahara Desert to the northern coastal strip where over 90% of the population lives, as shown in Figure 1and 2.

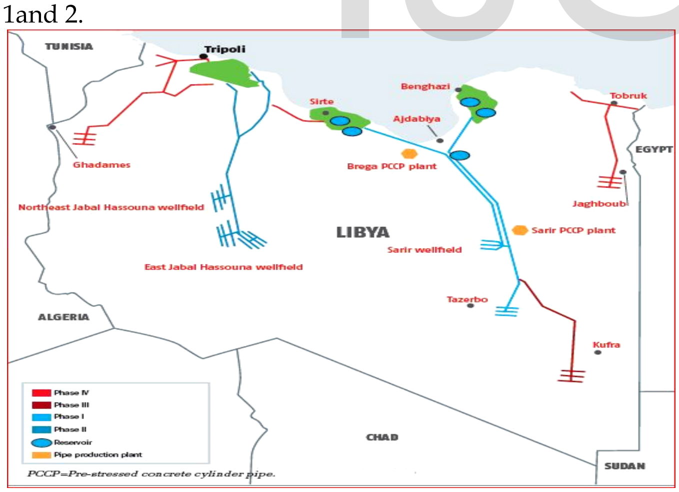

Figure 1. GMMR Project Phases

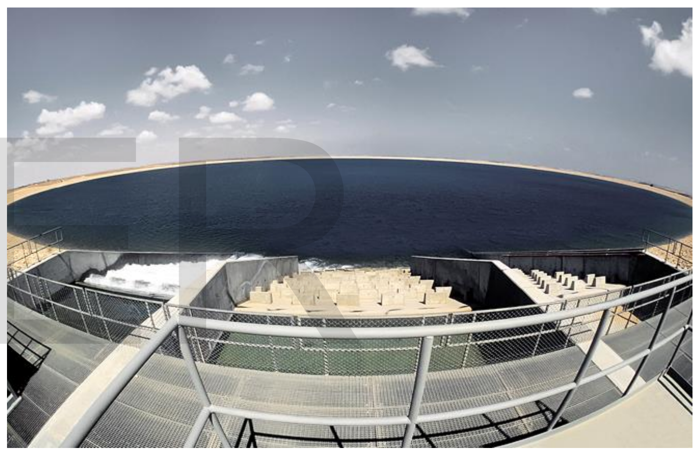
Figure 2. Sirte End Reservoir

Sirte end reservoir has been protected against corrosion by using a cathodic protection technique. Cathodic protection (CP) is one of the most common methods to prevent corrosion of metallic structures such as pipelines or tanks used to transport and store gas, oil, or water, this is generally applied as a secondary corrosion protection method as a back up to the primary protective coating. Cathodic protection can be achieved by sending a current into the structure from an external electrode and polarizing the cathodic sites in an electronegative direction. Cathodic protection essentially reduces the corrosion rate of a metallic structure by reducing its corrosion potential, bringing the metal closer to an immune state.[1] There are two main types of CP systems, namely, the sacrificial anodes and impressed current cathodic protection system. Impressed-current systems employ inert anodes and use an external source of DC power to impress a current from an external anode onto the cathode surface. In a sacrificial anode cathodic protection (SACP) system, the protection of

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pipeline, for example, is achieved by connecting the pipeline structure to a sacrificial anode, which is placed close to the protected pipeline. A sacrificial anodes are made from active metals such as magnesium, zinc, or aluminum, which are considered the most active metals according to the galvanic series. Cathodic protection current is created by the potential difference between sacrificial anodes and the protected pipeline structure. The type of anode used depends on electrolyte resistivity and the chemical compositions of the electrolyte to which the substrate is exposed. For pipeline, sacrificial or galvanic anodes are generally used in cases where relatively small amounts of current are required (typically less than 1A) and areas where soil resistivity is low enough (typically less than 10,000 ohm-cm) to permit obtaining the desired current with a reasonable number of anodes. The anodes in sacrificial anode cathodic protection systems must be periodically inspected and replaced when consumed.[2,3] The objective of this work is to understand and explain the main role of the cathodic protection in protective of the underground steel structure, in addition to the pipe-to-soil potential measurements to evaluate the extent of cathodic protection performance on the metal structure. Generally, the cathodic protection system aims to polarize a pipeline to a minimum protective potential according to steel pipeline criteria. The polarized potential is to be measured through test stations, which are to be installed at a locations along the route of pipeline.

2 Field Work

2.1 Materials

Table 2.1 shows the materials types that are used in the sacrificial anodes cathodic protection system.

Table 2.1 The Materials Used in SACP System

Pipe type	PCCP (By Pass)& Carbon Steel(Inlet/Drawdown)
Ground bed (Anode type)	Sacrificial Zinc & Magnesium
Backfill (anode)	75% Bentonite ,20% Gypsum,5% Sodium Sulfate
Reference Electrode Type	Copper -Copper Sulfate Reference Electrode(CSE)
Digital Voltmeter Type	High Impedance Voltmeter (AVO)

2.2 The Components of Sacrificial Anode Cathodic Protection Method

2.2.1 Voltmeter with adequate input impedance

To determine a pipe-to-soil potential value, a voltmeter must measure across an external circuit resistance, which may vary widely from one environment to another and referred to it as multimeter, Figure 2.1 shows MEGGER M-8035 dual display multimeter which is designed to provide greater accuracy with additional extensive measuring capabilities. In addition, two color-coded meter leads with clips for connection to the pipeline and reference electrode.

2.2.2 Reference Electrode

The copper-copper sulfate reference electrode is the most common use in the field to measure the potential of buried pipelines. Figure 2.2 demonstrates Cu-CuSO4 half-cell electrode. The reference electrode consists of a plastic tube holding the copper rod and saturated solution of copper sulfate. A porous plug on one end allows contact with the copper sulfate electrolyte. The copper rod protrudes out of the tube. A voltmeter negative lead is connected to the copper rod.[4]

Figure 2.1. High input impedance digital voltmeter

Figure 2.2. Cu-CuSO4 half-cell electrode

2.2.3 Ground Bed

The most commonly used materials for sacrificial anodes on buried pipelines are alloys of magnesium and zinc. In the inlet and draw down pipelines of the reservoir there are 34 magnesium anodes distributed over 4 ground beds and 18 magnesium anodes distributed over 1 ground bed, respectively . The potential of magnesium anode is about -1500 mV according to copper-copper sulfate reference electrode ($Cu/CuSO_4$). The by-pass pipeline has 70 zinc anodes which are divided into 4 ground beds and the potential of zinc electrode is -1100 mV according to copper-copper sulfate reference electrode.

2.3 Measurement Procedure and Survey Method

The most widely accepted method of measuring cathodic protection levels on pipelines is structure-to-electrolyte potential measurement using a portable copper-copper sulfate electrode. The 100-mV Polarization/Decay criterion is used as acceptable in the National Association of Corrosion Engineers (NACE) SP0169 "Control of External Corrosion on Underground or Submerged Metallic Piping Systems". This criterion states that adequate protection is achieved with "a minimum of 100 mV of cathodic polarization between the structure surface and a stable reference electrode contacting the electrolyte. The formation or decay of polarization can be measured to satisfy this criterion." Pipe-to-soil potential measurements are performed by placing the electrode over the pipeline for readings. The porous plug, with cap removed, should be in firm contact with moist earth. This may require digging in at places where the earth's surface is dry. In extremely dry areas, it may be necessary to moisten the earth around the electrode with fresh water to obtain good contact. Do not permit grass (particularly when wet) to contact exposed electrode terminals because that may affect the observed potential. The reference electrode will be connected to the negative terminal of a high impedance voltmeter and the positive terminal to the pipeline (via test point terminal, probe rod, or direct contact with pipeline), as shown in Figure 2.3. The half cell reference electrode is placed on the ground surface directly over or closely adjacent to the pipe, a change in potential will be noted when the electrode is moved along the line.[5] On the other hand, A current shunt is one of three methods that can be used to obtain a current measurements. The method for calculating current is to determine the amps/millivolts rating of the shunt, the electrical shunt is shown in Figure 2.4. There are two values associated with the shunt, one in amps and the other in millivolts. Except for wire-type shunts, most shunts will have these values stamped on them. The amps/millivolts rating can be determined by dividing the amp value by the millivolts value. This calculation gives how many amps are flowing per millivolts measured across the shunt. After measuring the millivolts drop across the shunt, multiply the millivolt drop by the amps/millivolt rating to get the current flow through the shunt in amperes.

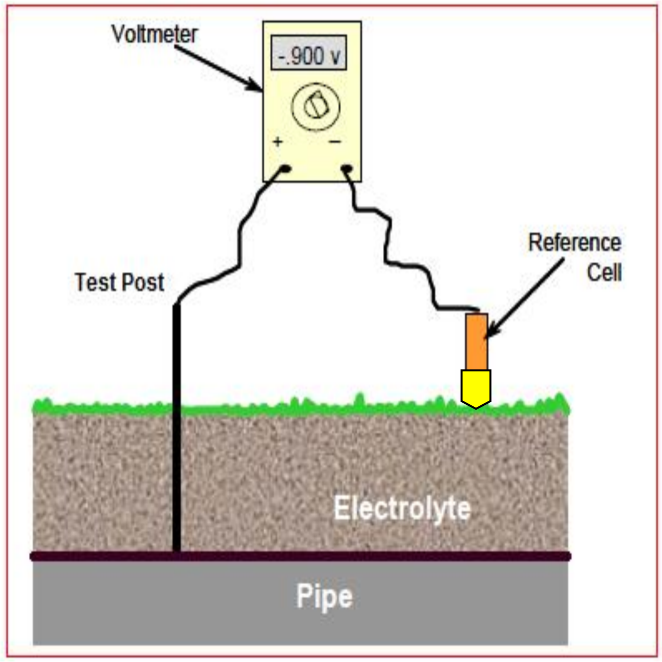

Figure 2.3. Pipe to soil potential measurement.[5]

Figure 2.4. Shunt- junction box for CP

3. Results and Discussion

3.1 Inlet Pipeline

The protection of the inlet pipeline of the reservoir is carried out by a number of 34 magnesium anodes divided into 4 ground beds, are shown in Table 3.3 to 3.6. There are also eight test points distributed in the area of the inlet pipeline of the reservoir, as indicated in Table 3.2. It can be

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seen from Table 3.1 that there was flow of an reverse current at the ground bed number four (G.B.No.4). In reference to the open circuit potential of the protection Mg-electrodes of the above mentioned ground bed, it was found that there was a significant reduction in the potential of the anode electrodes, which was less than the pipe potential after separation of the system for 48 hours, which explains the reflection of current flow. When the interference test was performed, it was observed that the protection potential readings were affected by the operation and the instantaneous separation, this indicates an overlap between the conveyance line and the inlet pipeline of the reservoir. It was observed at test point no.7 that the value of the potential at the instantaneous separation of the system is higher than when operating, as illustrated in Table 3.7. It should be noted that test point no.7 is specific to ground bed no. 4, which has a reverse flow current, as stated above. Furthermore, when the decay test was carried out and compared it with the readings obtained by the potential readings that were measured at the instantaneous separation of the system, the polarized potential of the protected pipeline structure was about -100 mV, the results are shown in Table 3.8. As for test point no. 7, the results were surprising and a reverse behavior was observed when the decay test was performed where a slight increase in the potential was observed opposite of what was expected.

Table 3.1 Ground Bed Performance For Inlet Pipeline of the Reservoir

Ground bed no.	Shunt (mV)	Current (A)	Comments
1	0.01	0.01	Shunt: 50amp=50mV
2	0.11	0.11	Shunt: 50amp=50mV
3	0.77	0.08	Shunt: 5amp=50mV
4	-0.73	-0.07	Shunt: 5amp=50mV
Total current	0.13 (amp)		

Table 3.2 Pipe to Soil Potential for Inlet Pipeline of the Reservoir

Test post	Potential (-mV)
Tp-1	620
Tp-2	567
Tp-3	600
Tp-4	697
Tp-5	571
Tp-6	568
Tp-7	520
Tp-8	824

Table 3.3 Ground Bed No.1

Anode No.	Potential (-mV)	Anode No.	Potential (-mV)
1	1158	6	1545
2	1581	7	1546
3	1583	8	1580
4	1538	9	1594
5	1519	-	-

Table 3.4 Ground Bed No.2

Anode No.	Potential (-mV)	Anode No.	Potential (-mV)
1	1092	6	1495
2	670	7	1553
3	1562	8	1586
4	1581	9	828
5	1539	-	-

Table 3.5 Ground Bed No.3 (Left side looking towards reservoir)

Anode No.	Potential (-mV)	Anode No.	Potential (-mV)
1	632	5	545
2	1480	6	569
3	1302	7	690
4	634	8	1353

Table 3.6 Ground Bed No.4 (Right side looking towards reservoir)

Anode No.	Potential (-mV)	Anode No.	Potential (-mV)
1	528	5	368
2	501	6	475
3	235	7	483
4	385	8	505

3.1.1 Interference Test

Table 3.7 Interference Test of Inlet Pipeline

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Test Post	On-Potential (-mV)	Off-Potential (-mV)
TP-1	615	600
TP-2	565	548
TP-3	597	590
TP-4	697	689
TP-5	566	553
TP-6	560	557
TP-7	520	521
TP-8	824	816

3.1.2 Decay Test

Table 3.8 Decay Test of Inlet Pipeline

Test Post	Off-Potential (-mV)	Decay Test (-mV)	Shift
TP-1	590	445	145
TP-2	536	409	127
TP-3	580	452	128
TP-4	630	529	101
TP-5	542	480	62
TP-6	536	410	126
TP-7	525	548	-23
TP-8	611	590	21

3.2 By- Pass Pipeline

The process of protecting the by-pass pipeline through the number of 70 zinc anode electrodes distributed on 4 ground beds, as shown in Table 3.9 and Table 3.11 to 3.14.. There are also 7 test points distributed along the bypass line, as demonstrated in Table 3.10. It was observed that there was stability in the current value with no reverse flow current and the results of the potential measurements for the protection anode electrodes were all at the required level and conformed to the required standards for the zinc electrodes. As shown from Table 3.15, when the interference test was performed, it was observed that the protection potential readings were not affected by the operation and the immediate separation. This indicates that there is no overlap between the conveyance line and the by-pass pipeline of the reservoir. When the potential measurements were taken at the instantaneous separation for all the test points and compared with the decay test measurements, as indicated in Table 3.16, a potential shift was observed but did not reach the desired amount except for test point no. 7 where the shift value reached more than 100 mV in the negative direction. This can be explained by the fact that the number of anode electrodes of protection are not enough to raise the protection potential at the by-pass pipeline. It can be cited here what happened in Benghazi reservoir where the number of anodes of protection has been increased to solve this problem.

Table 3.9 Ground Bed Performance for By-Pass Pipeline of the Reservoir

Ground bed no.	Shunt (mv)	Current (a)
1	0.15	0.15
2	0.16	0.16
3	0.54	0.54
4	0.49	0.49
Total current	1.34(amp)	

Table 3.10 Pipe to Soil Potential for By-Pass Pipeline of the Reservoir

Test post	Potential (-mV)
Tp-1	494
Tp-2	480
Tp-3	543
Tp-4	515
Tp-5	423
Tp-6	500
Tp-7	625

Table 3.11 Ground Bed No.1

Anode no.	Potential (-mV)	Anode no.	Potential (-mV)
1	1093	6	1053
2	1078	7	1054
3	1046	8	1055
4	1058	9	1052
5	1063	10	1022

Table 3.12 Ground Bed No.2

Anode no.	Potential (-mV)	Anode no.	Potential (-mV)
1	1034	11	1060
2	1031	12	1051
3	1059	13	1030
4	1045	14	1042
5	1047	15	1036
6	1012	16	1038
7	1031	17	1051
8	1014	18	1050
9	1002	19	1026
10	1052	20	1061

Table 3.13 Ground Bed No.3

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Anode no.	Potential (-mV)	Anode no.	Potential (-mV)
1	960	11	1079
2	1075	12	1077
3	1068	13	1079
4	1058	14	1086
5	941	15	1078
6	1057	16	1064
7	1073	17	1082
8	1075	18	1089
9	1076	19	1083
10	1071	20	1085

Table 3.14 Ground Bed No.4

Anode no.	Potential (-mV)	Anode no.	Potential (-mV)
1	1077	11	1071
2	1077	12	1072
3	1073	13	1068
4	1069	14	1069
5	1078	15	1070
6	1066	16	1073
7	1063	17	1098
8	1067	18	1073
9	1070	19	1070
10	1069	20	983

3.2.1 Interference Test

Table 3.15 Interference Test of By-Pass Pipeline

Test post	On-potential (-mV)	Off-potential (-mV)
Tp-1	494	494
Tp-2	485	485
Tp-3	538	538
Tp-4	510	510
Tp-5	420	420
Tp-6	499	499
Tp-7	618	618

3.2.2 Decay Test

Table 3.16 Decay Test of By-Pass Pipeline

Test post	Off-potential (-mV)	Decay test (-mV)	Shift
Tp-1	487	460	27
Tp-2	475	460	15
Tp-3	528	490	38
Tp-4	491	460	31
Tp-5	400	334	66
Tp-6	518	504	14
Tp-7	628	525	103

3.3 Draw Down Pipeline

The draw down pipeline has been protected by a ground bed containing 18 magnesium anodes and 2 test points distributed along the line. As shown from the results obtained in Table 3.17, the value of the current from the ground bed are shown in the negative direction. When the interference test was carried out, as illustrated in Table 3.20, it was observed that the protection potential readings were not affected by the operation and the immediate separation. This indicates that there is no overlap between the conveyance line and the draw down pipeline of the reservoir. When measuring the potential of the open circuit of the protection magnesium electrodes, a significant decrease in the potential value was observed. All the readings were not in accordance with the standards of the magnesium anode. This also explains the direction of the value of the current in the negative direction. When the decay test was performed as shown in Table 3.21 and the readings were compared with the instantaneous separation of the potential, a potential shift of more than 100 mV in the negative direction was observed .

Table 3.17 Ground Bed Performance For Draw Down Pipeline of the Reservoir

Ground bed no	Shunt (mV)	Current (A)	Comments
1	-0.01	-0.01	Shunt: 50Amp=50mV

Table 3.18 Pipe to Soil Potential For Draw Down Pipeline of the Reservoir

Test post	Potential (-mV)
Ts-1	610
Ts-2	595

Table 3.19- Ground Bed No.1

Anode no.	Potential (-mV)	Anode no.	Potential (-mV)
1	924	10	329
2	929	11	629
3	674	12	654
4	630	13	692
5	532	14	622
6	616	15	380
7	612	16	632
8	335	17	646
9	672	18	653

3.3.1 Interference Test

Table 3.20 Interference Test of Draw Down Pipeline

Test post	On-potential (-mV)	Off-potential (-mV)
Tp-1	615	615
Tp-2	600	600

3.3.2 Decay Test

Table 3.21 Decay Test of Draw Down Pipeline

Test post	Off-potential (-mV)	Decay test (-mV)	Shift
Tp-1	591	419	172
Tp-2	579	412	167

4. Conclusions

The main conclusions of this work are as follows:

- Cathodic protection system is a highly adaptable and effective means of preventing corrosion of underground structures.
- There is flow of an reverse current at the ground bed no. 4 belongs to the inlet pipeline of the reservoir.
- The potential readings by decay test are higher than the instant-off potential at the TP no. 7 for the inlet pipeline.
- The ground beds potential are in the required level for inlet pipeline of the reservoir.
- There is an reverse current flow at the ground bed no.1 for draw-down pipeline of the reservoir.
- All the anodes potential of the draw-down pipeline are not consistent with the standards of the Mg-anode.
- There are a potential shift reaching to more than -100 mV for draw-down pipeline of the reservoir.
- There is no reverse current flow for by-pass pipeline, and the potential readings of the Zn-anodes are at the required level.
- The potential shift did not reach the desired value for the by-pass pipeline except the test point no. 7.

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