Evaluation of Cathodic Protection System criteria On Constructed Tanks Over Bituminous Sand Mix Layer

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ABSTRACT

In the Oil/Gas production facilities, leaks in the Above-ground Storage Tank (AST) are a major threat. The majority of AST construction prior to 1980's, were over bituminous sand mix layer for levelling and to minimize the tank leakage due to the external corrosion of bottom plates. The bituminous sand mix layer partially shields the Cathodic Protection current from reaching the external bottom plate surfaces of the tank. Effectiveness of cathodic protection system on such tanks is evaluated and discussed in this paper.

Keywords: Tank external bottom plates, asphalt pad, cathodic protection, aboveground storage tank, AST, close distributed anodes, bituminous layer, protective potential measurement.

1. INTRODUCTION

Leaks due to corrosion of aboveground storage tanks (AST) at oil production, transportation, storage, and export facilities affect the petroleum industry adversely. External corrosion of AST bottom plates is one of the industry's primary concerns.

Above ground storage tanks (AST's) constructed before two decade at Kuwait Oil Company (KOC) were erected on continuous asphalt pad. Such tanks are still been in use at crude export tank farms, gathering centers and other production facilities of KOC.

This paper analyzes the effectiveness of cathodic protection system of tanks on asphalt pad based on the case studies conducted on three tanks during scheduled maintenance period of the tanks. Measurement of actual tank bottom surface protective potentials were undertaken that highlighted the drawbacks of routine potential measurement techniques for assessing effectiveness of CP for such tanks are discussed thoroughly in this paper. Effect of bituminous layer mixing ratio on Cathodic Protection of tank bottoms are correlated here with results obtained from case studies.

2. BACKGROUND

2.1. Asphalt Pad

Asphalt pad provided above properly compacted or stable soil can provide adequate support to the AST bottom plate. Such bituminous layer prevents exposure of tank bottom to the corrosive native soil. However, there may still be a collection of moisture between the tank bottom and asphalt pad due to condensation or ingress of moisture from periphery of the tanks. The accumulation of moisture can create a corrosive environment between the tank bottom and asphalt pad. A free draining asphalt pad or ring wall and a seal around periphery of the tank are normally considered in tank bottom design to eliminate the accumulation of moisture between the pad and tank bottom. However, the bituminous layer may hold the accumulated moisture resulting in exposure of the bottom surfaces to corrosive environment.

Unstable soil below the asphalt may induce cracks in the asphalt pad through which water and contaminants can penetrate to the steel tank bottom plate and provide a corrosive environment. Bituminous layer degrades with time and can provide a path for water and dissolved contaminants to come in contact with the tank bottom, allowing corrosion to occur[1].

Sand bitumen mix are normally batch mixed at an asphalt plant using approved sand (88%) and straight bitumen 60/70 (7%) with approved filler 5% and are delivered to the site ready for laying at a temperature of not less than 121 degree Celsius. After laying, the sand bitumen mix are properly compacted by hand driven self powered double vibrating rollers.

2.2. Cathodic Protection of External Bottom Plate of Tanks on Asphalt Pad

Asphalt may shield Cathodic Protection current in a manner similar to a disbonded coating on a pipeline. Cathodic Protection may or may not aid in stopping corrosion depending on resistivity of asphalt layer, composition and rate of degradation of bituminous layer, current drain to other structures such as pipelines, copper grounding grid / rods, etc.

Due to high resistance offered by bituminous sand layer between tank bottom surface and the anode ground bed on CP current path, majority of the CP current from a remote anode ground bed will flow to other structures such as piping & copper grounding grids, which are electrically continuous with the tank. Hence anode ground beds in close distributed fashion could be effective for such tanks.

Measurement of accurate tank bottom surface to soil potentials of such tanks is a challenge to the practicing CP professionals. For Tanks without permanent reference electrodes installed under the tank or when soil access holes are not available to access the bottom soil, tank to soil potentials are normally measured as shown in Figure-1. The measurement of potential is carried out along the tank periphery of tank using a portable type Cu/CuSO4 reference electrode. The measured potential will be resultant of the mixed potential of tank bottom surface and other structures such as piping and grounding grids rather than the actual tank bottom surface potential.

3. CASE STUDIES

Case studies were conducted during the scheduled maintenance period when portions (coupons) of tank bottom surfaces were cut for physical verification of corrosion on external soil side of the plates, where positioning of reference electrode (for CP potential monitoring) close to and on the same environment (bituminous layer) of tank bottom was possible.

3.1. Case Study - 1

A study was carried out on a 33 meter diameter tank with bottom plate wall thickness 10 mm constructed in 1992, resting on approximately 125 mm thick bituminous mixed sand soil. The tank was opened for scheduled mechanical inspection and was due for scheduled internal coating replacement. A Magnetic Flux Leakage (MFL) hand scan tool and ultrasonic scan was carried out to check the integrity of the bottom plate which indicated severe pitting corrosion on the soil side of the plate near the lap joints ranging between 1 mm to 10 mm. Figure 2 shows the percentage of metal loss (thickness) as obtained by MFL tool and ultrasonic scan. Furthermore a physical verification was carried out by cutting the plates at several lap joints which indicated pitting up to 10 mm (Figure-3).

As the tank does not consist of pre-installed permanent reference electrodes or soil access holes under the bottom plates, measurement of true potential below the tank bottom plate was not possible during the operational period. However when the coupons were cut for physical verification of corrosion of the external soil side of the plate, potential measurements were carried out by placing the reference electrodes close to the bottom plate as shown in Figure-4 & Figure-5.

The Tank was originally been protected by the remote type anode ground beds located outside the main plant fence. The exiting CP system was designed to protect the complete buried piping, other tanks in the gathering center (GC) and the subject tank as well.

As the protection level of tanks and the piping at this area was reported low during the latest routine potential survey, close distributed type anodes were installed along the periphery as part of CP system enhancement measures and the anodes were ready for commissioning.

Table-1. Potential Test Results of Case-1 Tanks

Sl. No	Location no.	Potential Measured, with reference electrode placed above Bituminous layer			Potentials Measured, with reference electrode placed below Bituminous layer			Potential measured, with reference electrode placed along the periphery		
		Natural	ON*	OFF*	Natural	ON*	OFF*	Natural	ON*	OFF*
1	Coupon-3 (Tank Centre)	-0.446	-0.519	-0.457	-0.528	-0.821	-0.590	-	-	-
2	Coupon-5 (near shell – East)	-0.465	-0.698	-0.527	-0.555	-1.003	-0.655	-0.628	-2.874	-0.805
3	Coupon-7 (near Shell – North)	-0.436	-0.807	-0.613	-0.543	-1.440	-0.747	-0.677	-2.675	-0.872
4	Coupon-10 (near shell – West)	-0.457	-0.733	-0.583	-0.548	-1.055	-0.702	-0.684	-1.884	-0.882
5	Coupon-12 (near shell – South)	-0.440	-0.741	-0.607	-0.529	-1.263	-0.750	-0.671	-1.914	-0.784
* Potentials with interrupting the dedicated TR with close distributed anodes along the periphery.										

In order to analyze the effect of Cathodic Protection current on the tank bottom resting above the high resistive bituminous sand layer, the close distributed anodes at the periphery was activated and potential results are summarized in Table-1, Figure-6, Figure-7 & Figure-8. As measured normally during routine potential survey, potentials measured at north, south, east and west side of tank periphery and the readings were compared with potentials obtained from the coupon locations close to the measurement. Since the remote ground bed had negligible effect on the subject tank and associated piping, the potentials obtained with remote ground bed in "ON" condition was considered as natural potential and these TR's remained "ON" during the ON/OFF survey (conducted by interrupting the dedicated transformer Rectifier provided for close distributed anodes).

Sample of bituminous sand were collected for lab test from the sections where the plates were cut. The results indicate the ratio of sand as 87%, bitumen as 12% with a moisture content of 0.4% and chloride content of 400 ppm. The resistivity of bituminous layer was measured with Wenner's 4-pin method[6] and the value was found to be 3,800,000 Ohm-cm. The bituminous layer resistivity was further measured with soil box method, by powdering the bituminous mix and adding a known quantity of de-ionized water to compare the results with bituminous layer used for other tanks, since, measuring the resistivity with four pin method was not possible on other tanks (case study-2) due to time and space constraints. The resistivity value of bituminous layer mixed with de-ionised water for this particular tank was found to be 1988 ohm-cm. Results of lab analysis is summarized in Table-2.

Table-2: Summary of Lab Analysis of Bituminous layer

Sl. No	Details	Case Study-1	Case Study-2	Case Study - 3
1	Year of Installation	1992	1993	1994
2	Tank Dia	32.92 m	82 m	33.53 m
3	Bottom plate thickness	10 mm	10 mm	10 mm
4	Pad	Bituminous sand	Bituminous sand	Bituminous sand
5	Pad Thickness	150 mm	150 mm	150 mm
6	% Sand in Pad	87	88	-
7	% Bitumen in Pad	12	10	-
8	% Moisture Content in Pad	0.4	0.7	-
9	Resistivity of pad	3800000 Ω cm	-	-
10	Resistivity of bituminous layer mixed with de-ionised water (measured with soil box)	1988 Ω cm	1072 Ω cm	-
11	Chloride content in Pad	400 ppm	350 ppm	-

Since the bottom plate had severe external soil side corrosion as indicated by MFL hand scan tool and ultrasonic scan (Figure 2), re-bottoming of tank was carried out by replacing the existing bottom plate & asphalt pad completely with new bottom plates and soil pad respectively. High Silicon cast iron anodes were installed underneath the tank bottom in distributed fashion and potential monitoring coupons and permanent reference electrodes were also installed underneath the tanks to measure tank bottom potentials.

After completion of re-bottoming works, potential survey was carried out separately with anodes distributed along the periphery Vs. anode distributed under the tank bottom. The survey results has shown that the tank was effectively protected by Cathodic Protection according to -850mV CSE criteria[2,3,4,5] with anodes distributed along the periphery as well as those distributed below the tanks[7].

3.2. Case Study – 2

Another study was carried out on 82 meter diameter tank with bottom plate wall thickness 10 mm constructed in 1993 resting on approximately 125 mm thick bituminous mixed sand soil. The tank was opened for scheduled mechanical inspection and was due for scheduled internal coating replacement. A MFL hand scan tool and ultrasonic scan was carried out to check the integrity of the bottom plate which indicated corrosion on the soil side of the plate near the lap joints ranging between 1 mm to 4 mm. Furthermore a physical verification was carried out to analyze soil side corrosion, by cutting the plates at several lap joints which indicated pitting up to 4 mm.

Table-3: Potential Test Results of Case-2 Tanks (measured at locations where section of tank plate is removed)

Sl. No	Location no.	Potential Measured above Bituminous layer*		Potentials Measured below Bituminous layer*		Remarks
		ON	OFF	ON	OFF	
1	Coupon-1	-1.17	-1.08	-1.16	-1.08	Tank-Center
* Potentials (Volts w.r.t Cu/CuSO4 reference electrode) by interrupting the TR with remote anode ground bed						

As the tank does not consist of pre installed permanent reference electrodes or soil access holes under the bottom plates, measurement of true potential below the tank bottom plate was not possible during the operational period. Potential measurements were carried out while one portion (coupon) of bottom plate was removed, by placing the reference electrodes close to the bottom plate as shown in Figure-4 & Figure 5. Potentials obtained by placing the reference cells at the bituminous layer (Figure-4) and below the bituminous layer (Figure-5) are tabulated in Table-3 & Figure 9. As normally measured during routine potential monitoring survey, potential results obtained by positioning reference electrodes along the periphery are summarised in table 4 & Figure 10.

Table-4 Potential Test Results of Case-2 Tanks (measured along tank periphery)

Sl. No	Location no.	Potential Measured along tank periphery	
		ON	OFF
1	East	-1.250	-1.175
2	West	-1.197	-1.065
3	South	-1.295	-1.183
4	North	-1.209	-1.08
* Potentials (Volts w.r.t Cu/CuSO4) by interrupting the TR with remote anode ground bed			

Sample of bituminous sand were collected (from the sections where the plates were cut for physical verification) for lab test, the results indicated the ratio of sand as 88% and bitumen was 10% with a moisture content of 0.7% and chloride content of 350ppm. The resistivity value of bituminous layer mixed with a known quantity of de-ionised water, measured at lab utilizing soil box method, was found to be 1072 ohm cm.

Lab analysis results of Case study -1 and case study-2 tanks are summarized in Table 2.

3.2. Case Study – 3

A wet crude tank inside a gathering with 33.5 meter diameter, with bottom plate thickness of 10 mm constructed in 1994 resting on approximately 125 mm thick bituminous mixed sand soil was also selected for analysis of CP effectiveness. The tank was opened for scheduled mechanical inspection and was due for scheduled internal coating replacement. A MFL hand scan tool and ultrasonic scan was carried out to check the integrity of the bottom plate which indicated corrosion on the soil side of the plate near the lap joints ranging between 1 mm to 4 mm. Furthermore a physical verification was carried out to analyze soil side corrosion, by cutting the plates at several lap joints which confirmed pitting up to 4 mm.

Table-5. Potential Test Results of Case-3 Tanks

Sl. No	Location no.	Potential Measured, with reference electrode placed above Bituminous layer		Potentials Measured, with reference electrode placed below Bituminous layer		Potential measured, with reference electrode placed along the periphery	
		ON*	**OFF***	**ON***	**OFF***	**ON***	**OFF***
1	Coupon 1 (near Shell – North)	-1.148	-0.848	-1.570	-1.030	-1.834	-1.150
2	Coupon-2 (Tank Centre)	-1.557	-1.074	-1.551	-1.062	-	-
3	Coupon-7 (near Shell – East)	-1.205	-0.984	-1.673	-1.054	-1.738	-1.024
4	Tank periphery - South side (out side tank)	-	-	-	-	-2.046	-1.090
5	Tank periphery - West side (out side tank)	-	-	-	-	-1.672	-1.170
* Potentials with interrupting the dedicated TR with close distributed anodes along the periphery.							

As the tank does not consist of pre installed permanent reference electrodes or soil access holes under the bottom plates, measurement of true potential below the tank bottom plate was not possible during the operational period. Potential measurements were carried out while portions (coupon) of bottom plate was removed, by placing the reference electrodes close to the bottom plate as shown in Figure-4 & Figure 5. Potentials obtained by placing the reference cells at the bituminous layer (Figure-4) and below the bituminous layer (Figure-5) are tabulated in Table-5. As normally measured during routine potential monitoring survey, potential results obtained by positioning reference electrodes along the periphery are summarized in table 5

4. OBSERVATIONS AND DISCUSSIONS

For case study-1 tanks, tank bottom to soil potentials measured with remote anode ground bed operating, are assumed as natural potential, since the existing remote bed system had negligible effect on the tank bottom potentials. The existing CP system with remote anode ground bed was in-effective in protecting the case study-1 tank bottom plates and associated piping.

For tanks with bituminous sand layer (asphalt pad), location of reference electrodes is vital in measuring the accurate tank bottom potential.

For Case-I tanks, as evident from Table-1 and Figure-6, Figure-7 & Figure-8, there is a substantial difference in potentials which is measured by placement of reference electrode at various locations (Figure-1, Figure 4 & Figure 5). For accurate tank bottom potential the reference electrode need to be placed in the same environment of tank bottom, i.e., the bituminous layer (Figure-4). Locating the reference electrode at the bituminous layer may not be possible during normal operating conditions of tank. Potential measured along the periphery or at the sand under the bituminous layer (during scheduled maintenance period) are resultant of mixed potentials of associated piping, grounding cables / rods & tank bottom potentials. Nevertheless, such mixed potential represent mostly of piping and other structures rather than the tank bottom, due to the high resistive bituminous layer appear in between the electrode and tank bottom. For example, polarized potential obtained by placement of reference electrode near to the periphery (Figure-1) at east side of tank was negative 805 mV $_{CSE,}$ however the actual potential (measured at coupon no. 5, above the bituminous layer) was only negative 527 mV $_{CSE}$. Furthermore, the surfaces have lesser or no polarization moving away from the shell towards tank centre.

This indicates that for case-1 tanks, the bituminous layer has a shielding effect on the CP current even by close distributed anodes installed along the periphery. Although the tank bottom plates has shown a polarization of 60 to 150 mV at locations close to the periphery (with measurements carried out by placing the reference electrode above bituminous layer), the tank centre had only achieved 10 mV polarization (Table-1 & Figure-8). Also the locations where bottom plate not making a good contact with the pad, especially at the lap weld joints, may be completely shielded from CP current.

Apart from expected variation in potentials similar to tank in case study-1, the potentials above and below the bituminous layer of case-2 tank was found to be same (Table 3 & Figure 9). Moreover the potential measured along periphery was also almost same to those measured above and below the bituminous layer (Table-4 & Figure-10). Comparison of chemical analysis of bituminous layers of both tanks indicates a slight variation in bitumen ratio exist between these tanks. Higher diameter of case-2 tank (82 m dia. of case -2 tanks have more surface area in contact, compared to 33 m dia. of case-1 tank), variation in composition of bituminous layer, higher degradation of bituminous layer of case-2 tank, etc. would have resulted in higher conductivity of bituminous layer of case-2 tank.

With the present operating conditions of power sources, potentials measured above the bituminous layer of case-3 tank indicate that the tank is receiving sufficient CP current to meet NACE -850 mV criteria. Hence the potentials mentioned in Table-5 which is measured along the tank periphery can be considered as a base line data to access the tank protection level during normal operation. For example, during normal operation, a recorded instant off potential of -1150mV CSE or higher along the periphery ascertain that the tank bottom is adequately protected by CP current.

This shows that tank bottom plate resting on bituminous layer can receive CP current depending on bituminous layer composition, involvement of other associated metallic structures, orientation of CP anodes, etc. which may vary from tank to tank.

In view of above, to determine actual protective potential criteria based on the potentials measured along the periphery, a correlation need to be made between the potentials measured by placing the reference electrodes along the periphery to those measured with reference electrodes placed on the bituminous layer. Such correlation need to be established for each tanks separately since the bituminous layer properties may vary from tank to tank as observed in case studies. Hence similar investigations need to be carried out on each tank those are constructed on asphalt pads during scheduled maintenance period. Tank bottom samples or coupons at representative areas can be removed for physical verification of external soil side corrosion of plates, subsequently the CP potential survey can also be carried out at those locations by placement of reference electrodes below and above bituminous layer, as discussed in the paper, in order to establish protective criteria based on the measurements made on the periphery.

Potential result of Case-2 and case-3 tanks indicates that tank is adequately protected with cathodic protection. MFL and ultrasonic scan results also ascertain the same, except for some minor corrosion at some areas which were repaired and tank was put back to operation without re-bottoming. Case-2 tank was located inside a tank farm which has lesser quantity of associated pipelines and other structures compared to case-1 tanks inside a gathering centre with congested piping and huge grounding networks. Also Case-2 tank was located near to the plant boundary, thereby capable of receiving adequate CP current from remote ground bed.

For Case-2 tanks, as the potentials measured below & above bituminous as well as those at periphery were equal, the potentials with reference electrodes placed at periphery can be utilized to evaluate protection level during normal operation.

5. CONCLUSION

Bituminous layer may shield CP current and is not desirable for effective protection against corrosion by cathodic protection.

External bottom plates of Tank already in use with asphalt pad can receive CP current with certain limitations. Anodes installed in close distributed fashion could be a better alternative compared to remote ground beds, for tanks with bituminous layer and especially the tanks located inside plant area with congested plant piping and grounding networks.

Measurement and analyses of protective potential for such tanks need to be carried out with utmost care to validate the protection level. Routine potential measurements carried out along the periphery of tanks may not indicate the actual (true) tank bottom surface potential due to the presence of high resistive bituminous layer and involvement of other associated metallic structures. Thorough investigations can be carried out during scheduled maintenance period of each tank to define CP protective criteria based on the routine potential measurement techniques.

Potential results, as obtained by routine potential survey technique for case-1 tanks does not indicate the true potential of the tank bottom surface which was verified with the measurement made by placement of reference electrode on the bituminous layer and close to the tank bottom surface. However, potentials obtained by routine survey methods for case-2 tanks proved to be adequate in assessing the true potentials. Compared to case-1 tanks, variation in composition of bituminous layer, higher diameter of case-2 tank, lesser quantity of associated piping & structures at Case-2 tanks, etc. were beneficial for case-2 tanks to receive sufficient CP current.

For case-3 tanks the potentials measured along the periphery during the study (Table-5) can be considered as the base line data to evaluate the cathodic protection level of the tank during normal operation.

6. REFERENCES

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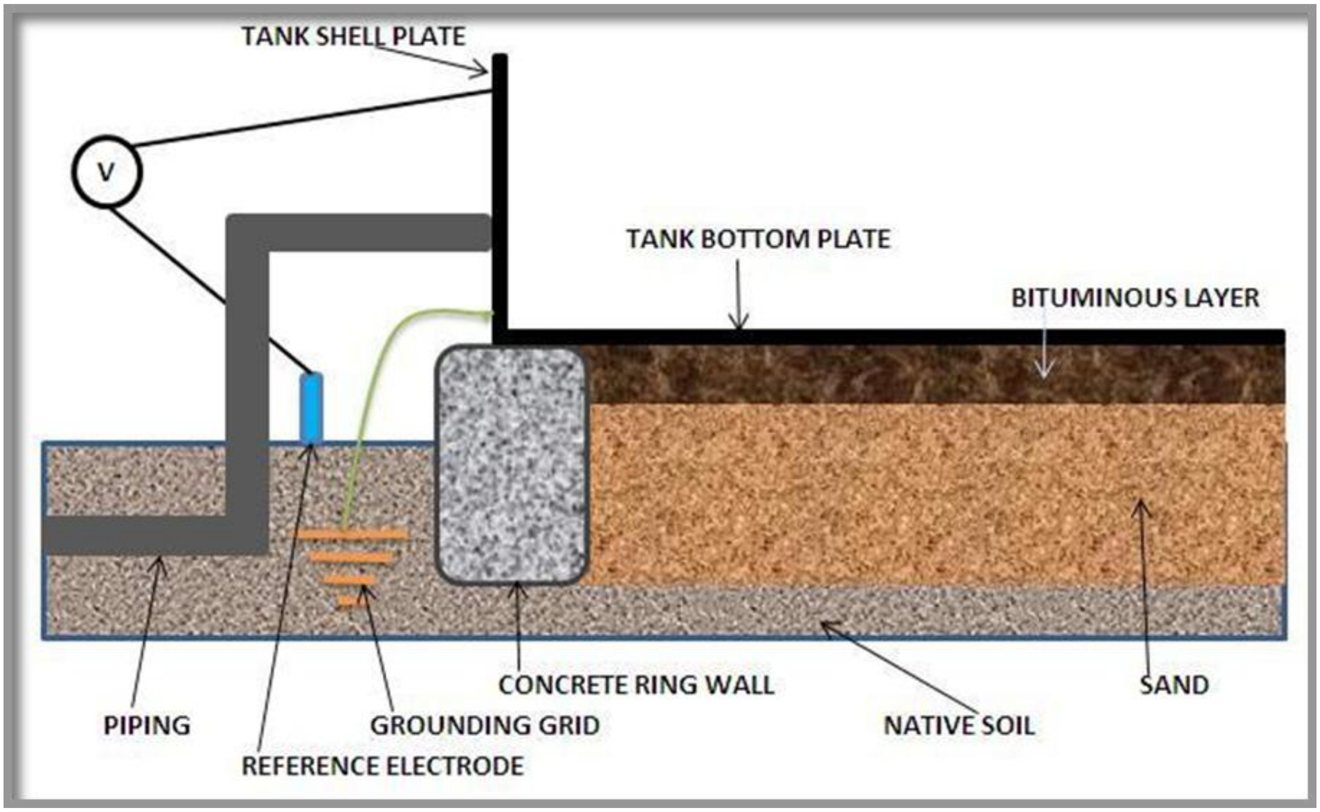
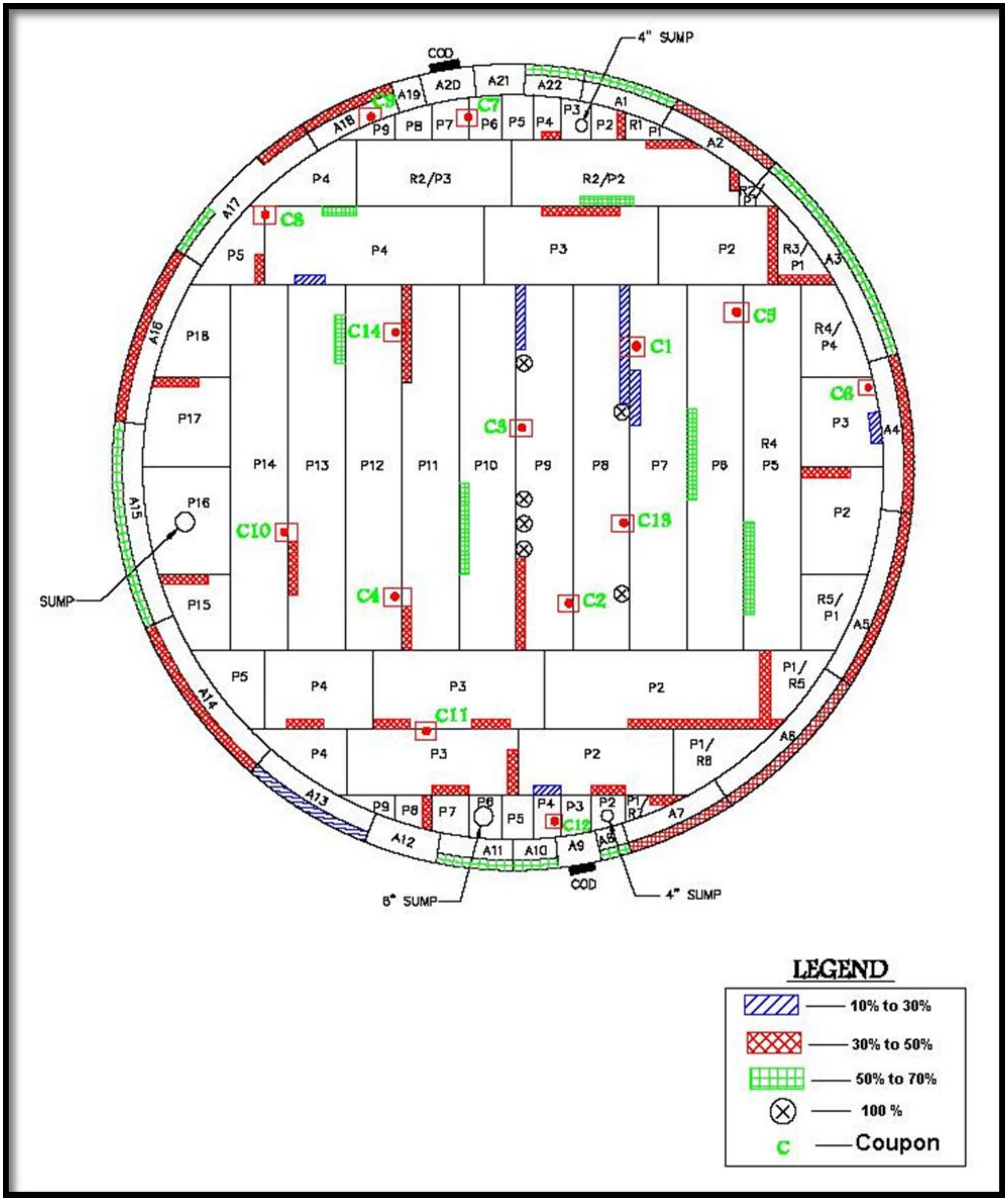
7. FIGURES

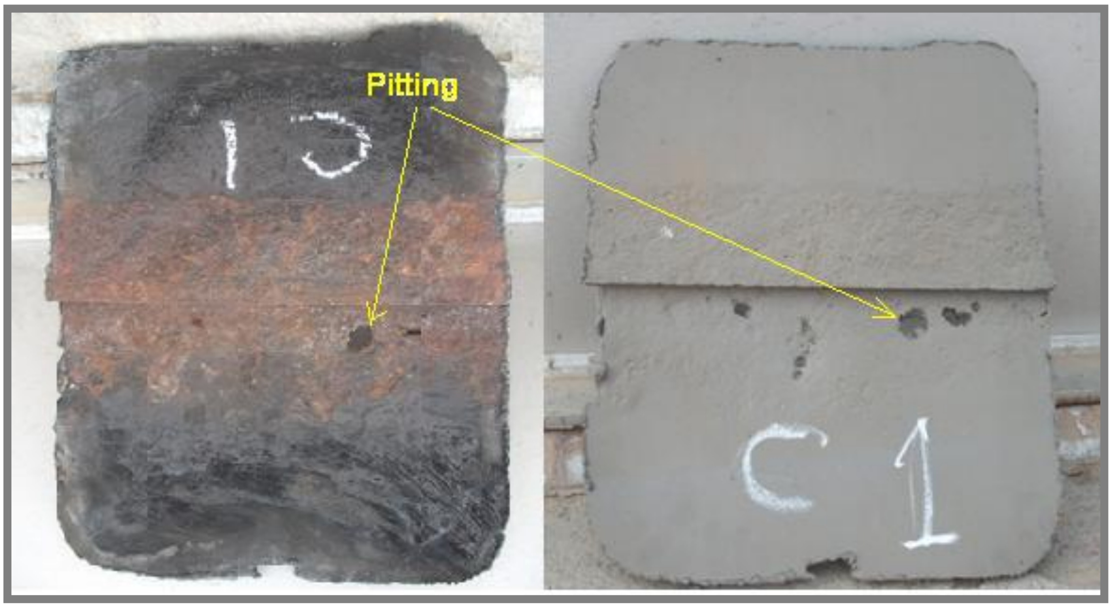
7.1. Figure-1 Potential measurement with placement of ref. cell along tank periphery



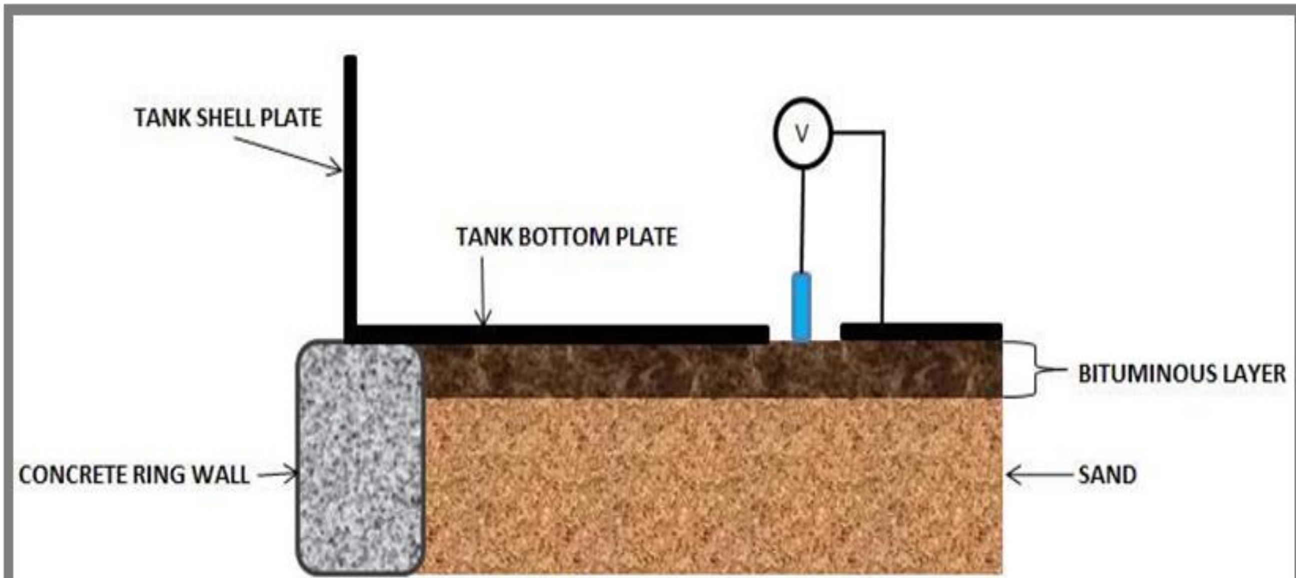
7.2. Figure-2 Metal Loss Indication with MFL and ultrasonic Scan (Case-1 Tank)



7.3. Figure-3 External soil side of bottom plate sample of case-1 tank

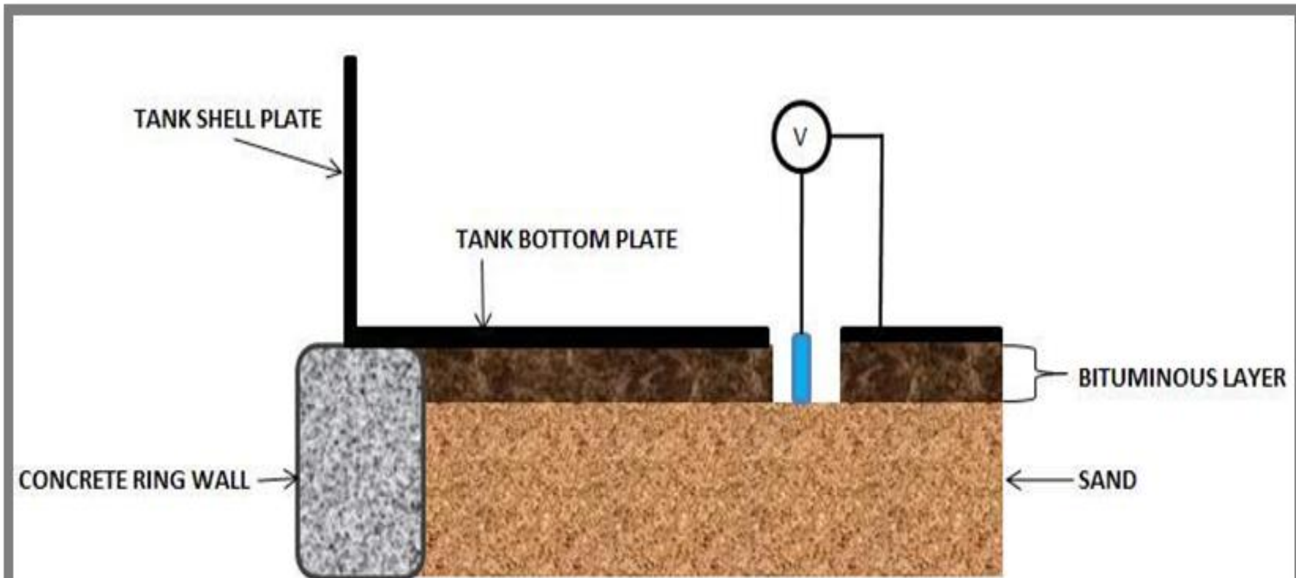


7.4. Figure-4 Potential measurement with placement of reference cell above bituminous layer



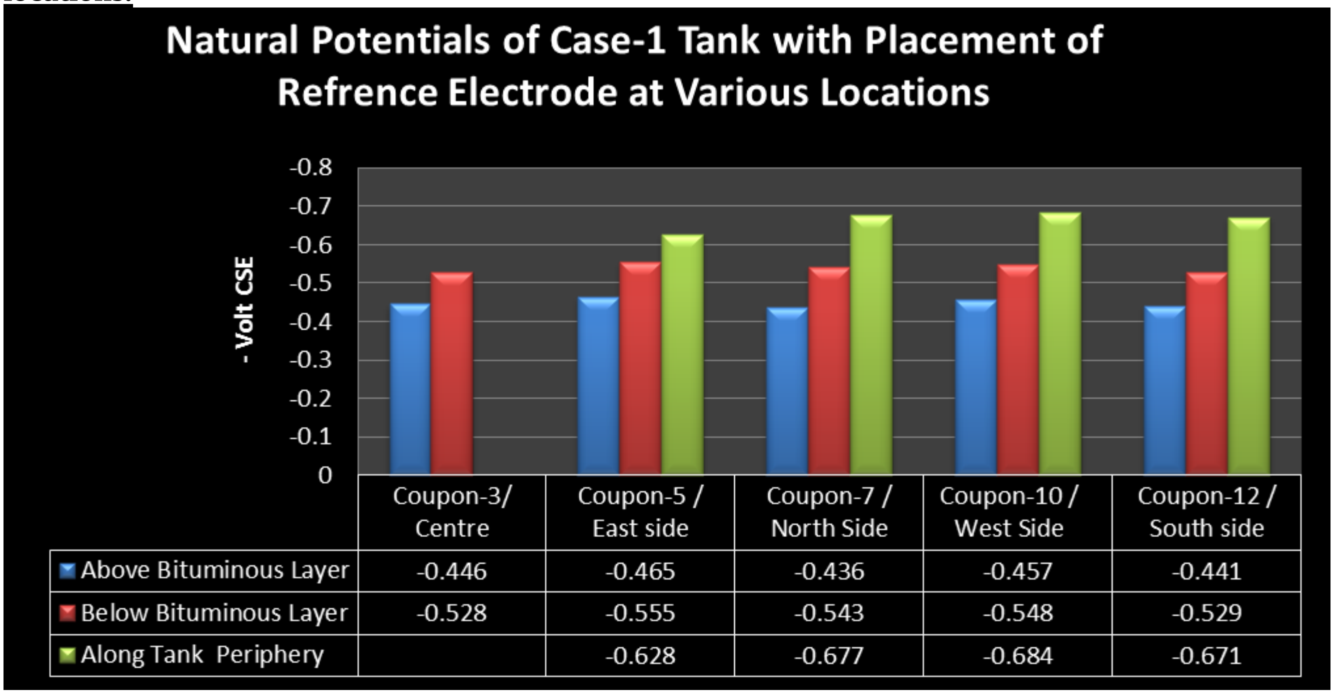
Potential Measured above Bituminous layer

7.5. Figure-5 Potential measurement with placement of reference cell below bituminous layer



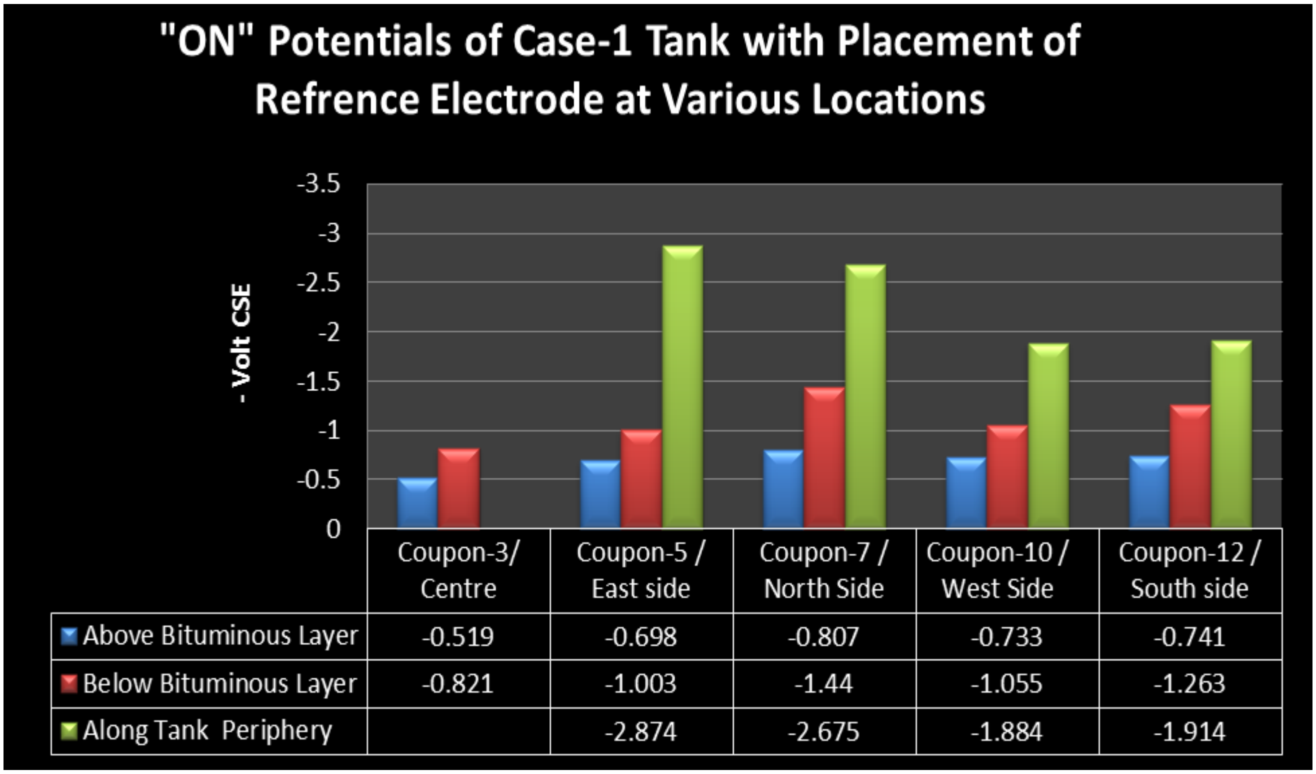
Potentials Measured below Bituminous layer

7.6. Figure-6: Potential results obtained with placement of reference electrodes at various locations.

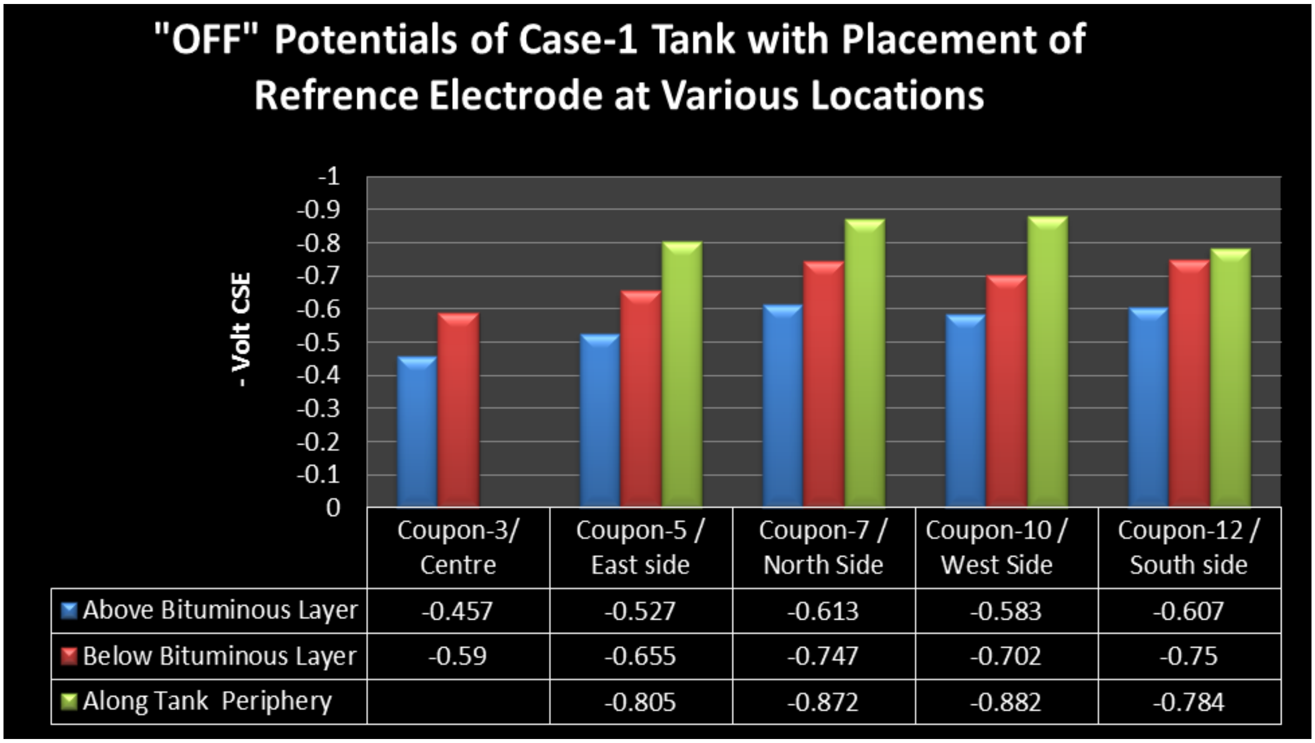


	Coupon-3/ Centre	Coupon-5 / East side	Coupon-7 / North Side	Coupon-10 / West Side	Coupon-12 / South side
Above Bituminous Layer	-0.446	-0.465	-0.436	-0.457	-0.441
Below Bituminous Layer	-0.528	-0.555	-0.543	-0.548	-0.529
Along Tank Periphery		-0.628	-0.677	-0.684	-0.671

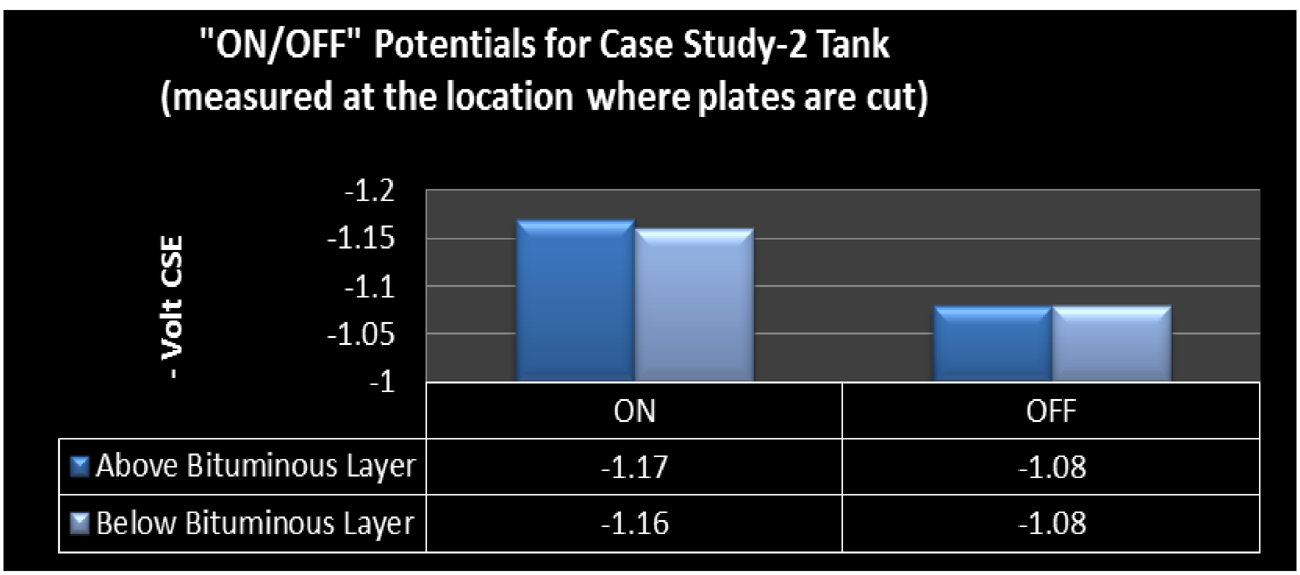
7.7. Figure-7: Potential results obtained with close distributed anodes at periphery



7.8. Figure-8: Potential results obtained with close distributed anodes at periphery.



7.9. Figure 9: Potential result obtained by interrupting the remote anode ground bed (Case Study-2)



<u>7.10. Figure10 Potential result obtained by interrupting the remote anode ground bed (Case Study-2)</u>