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## Design of an Ionic Conductor as Permanent Electrode for Monitoring Cathodic Protection System performance.

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**Abstract**

The most dominant used method for protecting the bottom of a tank is impressing a current cathodic protection (ICCP). Monitoring the CP system is critical to maintain and extend the service life of the exterior bottom of the storage tank. The bottom of the tank usually located on or near the surface of the ground and in contact with materials used to support the tank and so presents a corrosion challenge. This work presents a successful design of an ionic conductor that can be used as a monitor procedure of ICCP system for ground storage tanks bottom. The new ionic conductor system offers an accurate and efficient performance compared with old copper/ copper sulphate electrode monitoring system. The risks failure of permanent electrodes including cables disconnection and electrode dryness are increasing. Ionic conductors were used to insure proper potential monitoring. The new ionic conductor system scheme has the features of lower cost and less installation time over conventional methods.

KEYWORDS: ICCP; Storage Tanks; Permanent Electrode; Ionic Conductors.

## 1. Introduction

Corrosion is the process of an electrochemical reaction between the structure of a mineral (such as a tank) and its environment (such as soil), and this leads to a difference in the properties of the metal and ultimately the failure of the structure. CP is a powerful tool for mitigating corrosion failure, especially in steel structures such as underground pipes, tanks, pallets, pile sheets, etc**.** Direct electric current (DC) on the metal surface. [1, 2]

CP system consists essentially of [3-5]''.

1- Cathode, it is the metal to be protected.
2- Anode, it is the metal put intentionally to corrode in place of cathode and
3- DC current source.

Current from the cathode to the anode flows electronically through a conductor cable, and the circuit is completed from anode to cathode ionically through surrounding electrolyte media. There are two types of CP systems [4-9]''.

1 - Sacrificial Anode System (SAS), where the anode has a lower natural potential than the cathode, the required DC is generated by the action of the battery

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between the two poles (anode & cathode figure 1. [10]''.

2- Impressed Current System (ICS), A DC is supplied by an external source is required figure2.

Since CP systems were first applied, engineers have used extensive experience and monitoring to improve their anti- corrosion design. The Correct position and current output of anode beds are topics of vital importance to the performance of the CP system as a whole.

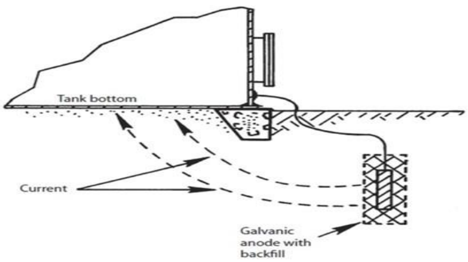



Fig. (1) Sacrificial Anode System (SAS).

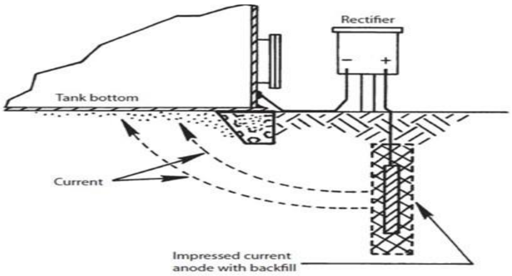



Fig. (2) Impressed Current System (ICS).

The permanent electrode copper/ copper sulphate Cu/$CuSO_4$ in the cathodic protection were played main important factor for monitoring, This was carried out through intensive experience engineering for monitoring through optimizing the design to mitigate corrosion, also the correct position and current output of anode beds are subjects of vital importance to the performance of the CP system as a whole figure 2. [10, 11, 12]''

The standard method for determining the effectiveness of cathodic protection on the bottom of the tank is the potential measurement from the tank to the soil. These measurements are performed with a high-impedance voltmeter and a stable, reproducible reference electrode in contact with the electrolyte [13, 14]''. These measurements are commonly made with the reference electrode placed in contact with the soil at several places around the perimeter of the tank and, if possible, at one or more points under the tank. Under tank, measurements are made because measurements at the perimeter of the tank may not represent the tank-to-soil potential of the centre of the tank bottom. One problem associated with monitoring cathodic protection systems at the bottom of the tank is the inability to place a portable reference electrode too close to the underside [15]''. For new tank construction, permanent reference electrodes are installed which are subjected to dry out by time and wire lead disconnection [10, 16]''.

The experimental work is aimed through design an ionic conductor to monitor the potential at different locations underneath and around the perimeter of a design small mild steel tank in order to measure the efficiency of the protection. External ICCP system was applied. A design small mild steel tank in order to simulate to large size tank. And in this work studied a new design engineering of ionic conductor for monitoring of impressed current cathodic protection system. The potential of cathodic protection at bottom tank was measured at different locations through ionic conductors. The measuring of potential was measured at period time 4 months at everyday interval. The results were recorded and discussed.

## EXPERMENTAL

### A. System Design and Preparation:

The system consists of several parameters as follows:

1- Carbon steel tank, the mild steel tank with a diameter 1m and height 1m is fabricated and which is used as examined unit showed in figure 3.


Fig. (3): Tank Assembly.

2- Graphite anodes (canister) and carbonaceous backfill are shown in figure 4and figure 5. It contains the three carbon anodes that are connected to the rectifier circuit.

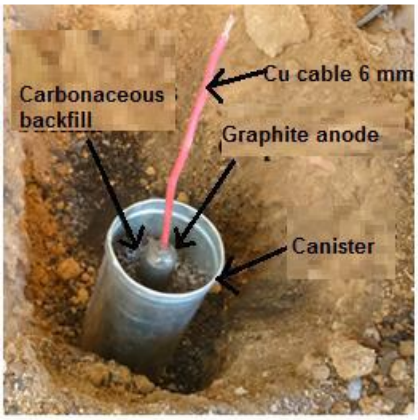



Fig. (4): Graphite anodes (canister) and carbonaceous backfill.

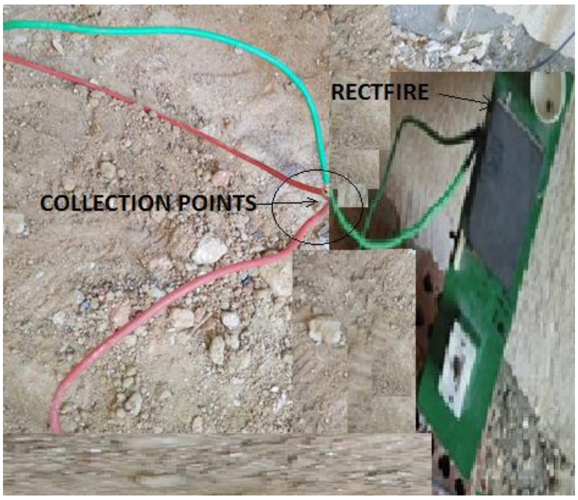



Fig. (5): Collected three copper wires at the same point and with rectifier.

3- DC power supply: A constant stable DC supply was obtained through a stabilized, electronically controllable power supply with power –IC. The voltage range (1.2 – 30) V and the current 2.0 A. The transformer (24V /2A) was used to step down the domestic power supply of 220 V/AC source to the required DC range figure 6.

Fig. (6) Transformer

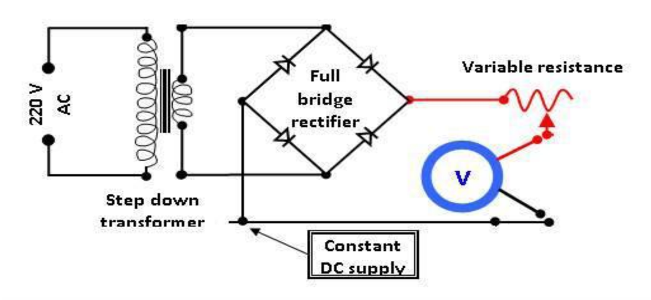
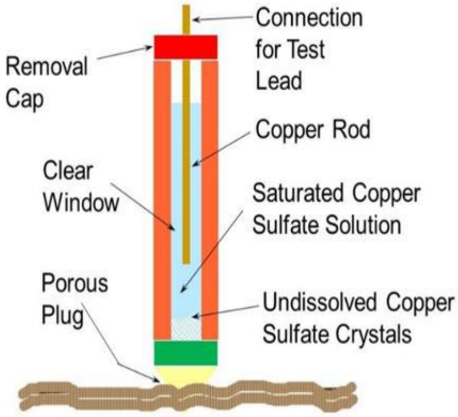



Fig. (7) Rectifier Circuit.

4- ($Cu/CuSO_4$) portable reference electrode is showed in figure8. This electrode is used for measurements potentials on steel structures. [17]’’




(a) Electrode layout


(b) Fabricated electrode.

Fig. (8): Layout and fabricated $Cu/CuSO_4$ Reference Electrode.

## B. Graphite anodes design, assembling and implementation:

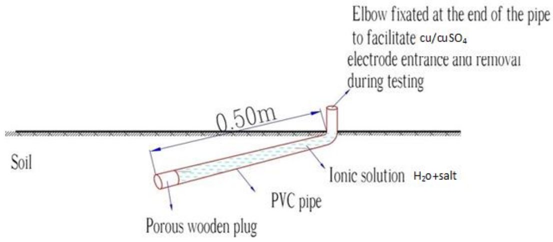
Graphite (carbon) since it's inert with its surrounding , and has a low consumption rate and perfect when connected to the rectifier to allow a kick start process of current flow in the anode. The carbon anode is 20 cm length, 39 mm diameter as showed atfigure9. And which is fabricated through a hole at the center middle of anode, the one terminal copper wire 10cm long of 6 mm diameters fixed into the anode hole with fabricated a steel washer by Araldite. After that, the 5 m of the same electrical wire welded the first terminal to the anode wire inside the junction PVC box, and the other terminal of three terminals of anode wires are collected with each other in one point. They were connected to the rectifier as showed at figure 5.


Fig. (9): Fabrication of three graphite electrodes.

Standard Carbon consumption rate = 0.3 kg / Amp. Yr. The collect of copper wires are connected with each other and insulation with a layer of Araldite, and then rapped with insulation tape for more protection.

## C. Design and Manufacture of Ionic Conductor:

The ionic conductors Figure7 are design and manufactured from three different length PVC duct diameter 5.08 cm, the one of terminal duct closed by natural porous materials and the other side is connected by L elbow, for fixing the Cu/CuSO4 electrode, while the pipe was filled by wet NaCl. Three PVC ducts (hoses) were placed in three different locations underneath the tank bottom to monitor the tank potential and ensure adequate protection.




a) Design of Ionic conductor


b) Ionic conductor's preparation.


c) Ionic conductor's installation.

Fig. (10) a, b and c: ionic conductor.

## D. Cathodic Protection System Design Data:

The external impressed current cathodic protection system of the above ground tank bottom was designed according to the international standards and specification methods [19-22]'', as follow:-

**[1.]** Tank surface area (SA)

Calculated of designed bottom Tank surface area to protect against any stray current as following equation:-

$SA = \pi r^2 = 22//7\times 0.5^2$ *(1)*

Where r = tank radius, r = 0.5m, *SA* is surface area to be protected= 0.785 $m^2$

**[2.]** Protection current (I)

The required protection current for bottom Tank surface area can be calculated through equation:

$I = SA*CD$ *(2)*

Where CD is current density $mA/m^2$= (20 $mA/m^2$),

Then the required protection current (I) = 0.785 * 20 =15.72 mA

Final current required *1.5 (safety factor) =23.58 mA.

**[3.]** Number of anodes required (N) based on Faraday's equation.

The number of anodes required through equation:

$(N) = (Y*I*C)/ W$ *(3)*

Where N numbers of anodes, Y: numbers of years. I: required protection current.

C: consumption rate of anode and W: weight of anode.

Consumption rate of anode =0.3 Kg/ampere. Year [10]''.

Then *N= (10* 0.02355* 0.3)/ 0.15=0.471= 1 anode.*

This means, the tank requires only a single centred anode weighing 150grams to protect it for 10 years, however we chose to design a distributed anode system for better current transfer to the tank and to maintain uniform protection all over the tank. Therefore we manufactured 3 carbon anodes, each weighing 150 grams making the total weight of anodes 450 kg. Since our total weight changed from 150 to 450 g, we needed to calculate the new adjusted protection lifetime. [18-21]''.

From equation 3, the protection life time is

*(Y) = (N*W)/ (I*C) = (3* 0.150)/ (0.02358* 0.3) = 63.6 years.*

The anodes must be distributed in a system under the tank to maintain current distribution and uniform polarization all over the tank bottom as showed at figure 11.

Fig. (11): Anodeslay-out.

Fig. (12) Canister lay-out.

Anodes Resistance for vertical ground bed

According to Dwight's formula for a single vertical anode:

$R = [(0.00521 * \rho) / L] * [\ln (8L / D) – 1]$ *(4)*

R = Resistance in ohms

L = Anode's backfill length in cm

D = Anode's backfill diameter in cm

ρ = Soil resistivity in ohm –cm

Then the Soil resistivity = 3200 Ω/cm (measured using soil resistivity meter) [22]''.

D= 15cm, L= 30cm

R= [(0.00521*3200) /30 *[ln (8*30)/15 -1] =69.2 Ω

.**Rectifier specifications**:

$V = I * R (total)$ *(5)*

When R (total) = R (anode) +R (Tank) +R (cables)

R (cables) can be neglected

$R (anode) = \rho/2d$ *(6)*

When ρ tank resistivity =16
R (anode) =69.2/3=23 then R (total) = 23+16=39Ω
Driving potential is the sum of all voltage drops at cathodic protection station.
Voltage drop = total required current * total resistance =0.01572*39=0.61308V.
Backup voltage = 2V it is the voltage difference between iron and carbon.
There v total = 2+0.61308=2.61308 volt.
Final current 15.72m A and final potential is 2.6V.

**CPS setting up for data acquisition:**
The ground soil was pure $2m^3$ sand ; the anodes were placed in canisters (D= 15cm, L= 30cm), filled with carbonaceous backfill with no voids around the anode, to ensure that much of the current reaching the anode is conducted the backfill by electric contact as showed at figure 11, 12. This enhances the consumption of backfill instead of anode and greatly extends the effective anode life. Carbon backfill also tends to reduce the overall circuit resistance by lowering the anode resistance to the soil [10]''.Cables was connected using splice kit for good insulation as showed at figure13.

Ionic conductor pipes were filled with compact salt slightly wetted with water and fixed in the soil facing the tank bottom in certain points showed in Figure 10 and figure 14.

Fig. (13): Splice kit for cables connections.

Fig. (14): Ionic Conductors Lay-out.

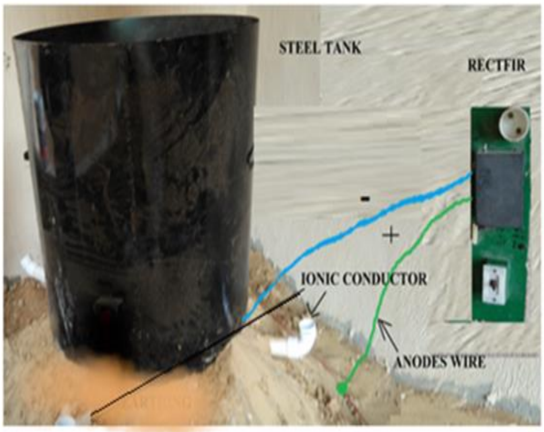



Fig. (15): Complete practical ICCP circuit.

The tank was placed on top of the soil. The measuring locations were marked and the tank connected to the rectifier showed in figure15.Measurement procedure was according to NACE standard to ensure high monitor efficiency [23]''.

**Results and Discussion**

Results Analysis and Discussion

The Stray currents originating from DC electrical systems may cause severe corrosion damage of buried metal structures, as carbon steel pipes, tanks or vessels. Nowadays, international standards establish the general principles to control DC interference and stop the effect of stray current and other media on the metal structure, which mainly based on potential and voltage gradients measurements over a 24 hours period.

The theory behind the ionic conductors is using a flexible PVC pipe or hose filled with very high conductivity media, which means no resistance sodium chloride slightly wet with water figure 10.One end of the hose is supplied with a porous stopper to allow the continuity between the soil and the ionic media figure 10(c). This end is to be fixed 5Cm depth in the soil underneath the centre of the tank Figure 14, and the other end will be outside the tank perimeter where the reference electrode is to be used to monitor the protection potential[19,20]''.figure 8(b) and 10(a).Instead of installing a permanent reference electrode underneath the tank, and weld tank wires to the bottom of the tank exposed to the soil, we placed three PVC pipes in three locations underground, which are illustrated in the following design figures14 and figure 15 and experimental figure16.

One pipe is located in the centre of the tank, the second one is located between point 1 and point 2 in 20 cm length under tank, and the third one is located between the point 5 and point 6 in 30 length under tank. The three PVC pipes are 2 " in diameter, but differ in length .the centred pipe is 0.5 m long while the second is 20 cm long and the third is 30 cm long. this is shown in Fig 16 these pipes will provide soil test points for our Cu/CuSo4 reference electrode to measure the tank's protected potential once the system is ON at different soil levels. The rule of ionic conductor in the cathodic corrosion protection impressed current systems were played main important factor, while the ionic conductor is more magnitude value for monitoring control. The impressed current cathodic protection must be controlled without any damage for save the cathode in ready state without happen corrosion damage. This was carried out through intensive experience engineering for monitoring through ionic conductor and optimizing the design to prevent any damage, also the correct position and current output of anode beds are subjects of vital importance to the performance of the CP system as a whole [20,21]''. The figure 17 is illustrated a complete cycle of impressed current cathodic with steel tank, ionic conductor, earthling and rectifier.

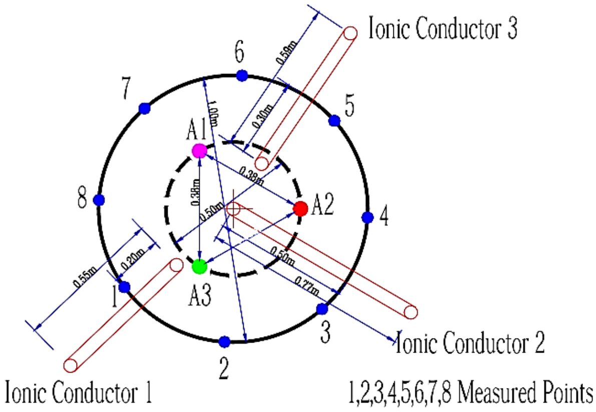



Fig. (16): Ionic conductor design location under the tank bottom.

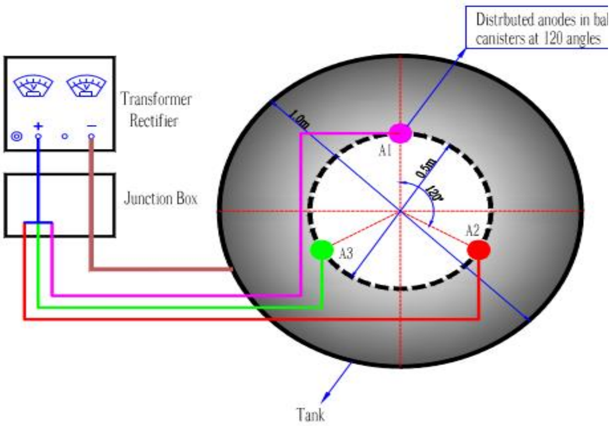



Fig. (17): Complete design ICCP circuit.

The data obtained from this work are recorded through 24 hours in 122 days and presented in figures18, 19.

Figure 18 is illustrated the relation between the potential and time (days) for three ionic conductors control of cathodic protection system, which is showed that the potential recorded clear in the range between -850 V to -1200 V. It is indicated that these conductors are worked in ideal condition.

While Figure 19 is indicated the relation between the potential and time (days) for eight points around the tank bottom control of cathodic protection system, which is showed that the potential recorded clear in the range between -850 V to -1200 V. It is indicated that the impressed current cathodic protection system was working in ideal condition. After that the tank was inspected and showed that no damage at the bottom and shell of the tank.

These results are indicating that the stray current don't effect on the steel structure of tank bottom and shell. Then these studies are approved that the ionic conductor is improvement the inspection and control the impressed current of cathodic protection.

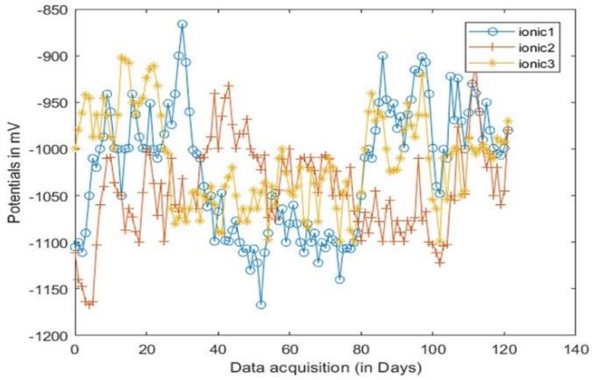



Fig. (18): Potential measurements of three ionic conductors for control of cathodic impressed current protection through 122 days.

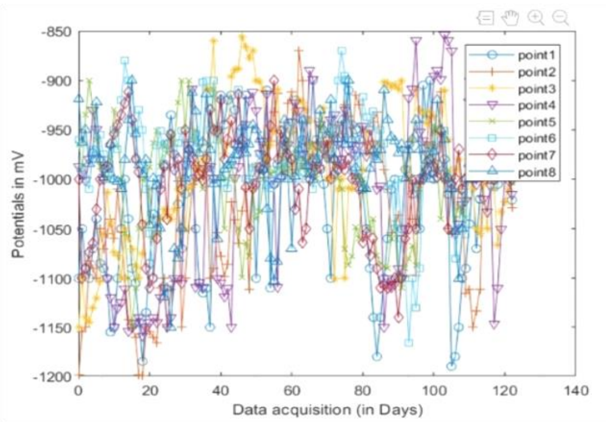



Fig. (19): Potential measurements of eight points for control of cathodic protection system through 122 days.

**Examination of these data reveals the following results for the studied system configurations:**

1- Natural tank/ soil potential measurements at the beginning were taken at the tank perimeter and at the ionic tube entrance, shows a potential drop over the time as a result of the cathodic polarization which decreases corrosion current and therefore the corrosion rate is decreased, Figure 20.

Fig. (20): Natural Tank/ Soil Potential Measuring at the Perimeter

2- Starting rectifier voltage = 10.16V, the current = 73mA which indicates high anodes resistance and high soil resistivity.
3- Tank/ soil protection potential was measured for eight points at the perimeter,
Shows a well-protected system with minimum potential of -0.850 V and maximum of -1.2 V, Figure 17.
4- Tank/ soil protection potential was measured for three points at the ionic conductor ducts shows the same range of readings compared with the one at the perimeter with minimum potential= -0.866V and maximum = -1.17V, Figures 16.

## CONCLUSIONS

In view of the experimental results obtained from the present work one can conclude that measuring the effectiveness of the above ground tank cathodic protection system at its periphery does not usually represent the true potential at the tank center. Using permanent reference electrodes are installed which are subjected to dry out by time and wire lead disconnection. A successful design of a new ionic conductor refer to a PVC duct (pipe) filled with salt (NaCL) wetted with water that can be used as a monitor procedure of ICCP system for ground storage tanks bottom replaced under the tank at certain points to measure the protection potential efficiency of a CP system. The advantages of the new ionic conductor system offers an accurate monitoring by placing the reference electrode at its end. The new ionic conductor system scheme has the features of lower cost and less installation time over conventional methods, easy to refill with water and salt and the problems of an ionic conductor system can be controlled.

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