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External and internal cathodic protection of storage oil tanks

MOHAMED HALAFAWI[1*], NAWAR ABDULRAHMAN[2], LAZĂR AVRAM[3]

[1]Drilling and Production Engineering, Petroleum-Gas University of Ploiesti, Romania
[2]MSc, Mechanical and Electrical Engineering, Petroleum-Gas University of Ploiesti, Romania
[3]Drilling and Production Engineering, Petroleum-Gas University of Ploiesti, Romania

Abstract. The aim of this paper is to develop the cathodic protection system (CPS) for the internal and external face of a 2500 cubic meters (m^3) crude oil storage tank in order to prevent its body from corrosion and keep its integrity. External cathodic protection is done by 99.98 % Zinc (Zn) galvanic anodes while internal cathodic protection is achieved by 6.5 % Aluminum-Zinc (Al-Zn) galvanic anodes. A case study of an oil tank from the Romanian refinary field is taken to do the CPS. The total number of anodes required to protect the oil tank externally and internally are 20 and 123 anodes respectively. A sensitivity analysis study was done utilizing ANODEFLEX 1500 software in order to investigate the effect of changing the depth of anode place under the tank bottom. It was found that the deeper anode depth is, the longer anode spacing is along the total area of tank bottom.

Keywords: Cathodic protection, crude oil tanks, Al-Zn anodes, oil field study, and sensitivity analysis.

1. Introduction

Corrosion is one of the most seriously problems, in petroleum metal structures, that threat the petroleum processing plants where it attacks all the metal devices and equipment such as storage oil tanks, pipelines, separators, heaters, and all metal structures and machines. The corrosion is defined as an electrochemical process between a metal or an alloy and its surrounding environment which produces a gradually deterioration or destruction of the material and its properties [1-4]. The corrosion types are uniform attack, galvanic or two-metal, crevice, pitting, selective

*Correspondence address: halafawi_2008@yahoo.com

leaching, erosion, and stress corrosion [1-6]. Moreover, the conditions have to be present so as to occur the corrosion, are [1]:

- A metal capable of undergoing an anodic reaction-all metals
- An environment having a corrodant or cathodic reactant
- An electrolytically conducting environment
- A metal/environment conducting interface.

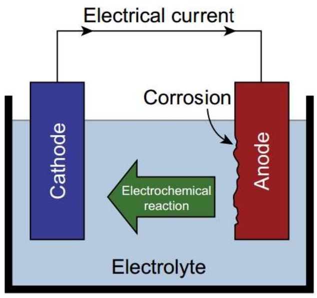


Fig. 1. Anodic and cathodic areas in a corrosion process [8]

Additionally, the damage of corrosion is highly effective, costly and dangerous; therefore it needs an effective corrosion control system. In order to prevent the corrosion and keep the equipment integrity, the following items should be implemented [1,3]:

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

The selection between the above items depends usually on economic considerations [1]. However, the electrochemical protection (cathodic and anodic protection) is extensively used and it is considered the effective way of mitigating the internal and external of oil field processing units. The cathodic protection (CP) is an electrochemical ways of corrosion mitigation techniques which use the electrochemical properties of metals in order to acertain that the metal unit, machine or device becomes the cathode of an electrolytic cell and hence it will be protected. Cathodic protection is achieved by an electric cell that appears between the metal to be protected and a more electronegative metal (outer surface of the anode) using the corrosive medium as an agent electrochemically. By coupling the anode to the metal an electrical cell is obtained which cathodically polarizes the metal to be protected. During this process the active anode is consumed, at a calculable rate, in favor of the protected metal. Types of CP are galvanic (sacrificial) anodes and impressed current systems [1-8]. Zinc, magnesium, and aluminum alloys are the common galvanic anode materials utilized. Zinc anodes are frequently utilized in low-resistivity brines due to their longer life. However, magnesium anodes are generally recommended for high resistivity waters. Aluminum alloy anodes have a lower driving potential

compared with magnesium, and provide a longer life in low-resistivity electrolyte [8]. On the other hand, high silicon-cast iron or platinized titanium anodes are the most common kinds of impressed current anodes utilized [8].
A mitigation of the corrosion for the oil storage tanks is required in order to prevent the storage tank failures. Cathodic protection is considered one of the most effective method to treat the oil tanks` corrosion and reduce its rates. The storage oil tank may corrode internally and externally. Protecting the oil tank components such as bottom plates, annular plates, shell courses and roof plates from corroding becomes extinsively required and beneficial for good operating practice and cost savings.
Therefore, the main objective of this article is to construct CPS for the internal and external face of a 2500 cubic meters (m^3) crude oil storage tank of a romanian processing field in order to to prevent its structure from corrosion. In order to implement internal and external CP, their mathematics should be expressed such as the protected surface area, current required, anode type selection and anode mass dimension, anode mass, calculation of the anodes` number, soil analysis corrosion and testing, calculation of groundbed resistivity, and calculation of dispersion resistance.

2. External Cathodic Protection

The CPS in processing field should designed to protect oil storage units from external corrosion resulting from galvanic effect due to different metals, zinc alloys, and magnesium alloys, also by different distribution and weights. The exterior of the tank, which comes in contact with the atmosphere, is subjected to widespread corrosion. Regardless of the destination of the tank, the flat bottom is also subjected to strong external corrosion as a result of differentiated aeration. The foundation on which the tank sits has a slight outward slope, of 1… 2% to facilitate the drainage of water and possibly of the products lost by leaking the bottom. It is covered with a waterproofing layer which also ensures leakage. The waterproofing layer is made of a mixture of sand and coal tar, for tanks that store petroleum products, or oil bitumen for other products and represents about 10% from the volume of the sand. The sand used is dry (maximum humidity 5%) and has a grain size of less than 2 mm. The sand is mixed with bitumen or tar at a temperature of 70 ... 80 ° C. After pouring, stretching, cooling and cylindering, the waterproofing layer is covered with a layer of 10 ... 20 mm thick fine sand. Before proceeding to making the bottom, the boards are covered with lead-based primer on the side that sits on the foundation. The lack of defects in the welding cords of the plates forming the bottom of the reservoir or the lack of defects caused by corrosion can be determined by the influx of ammonia under a pressure of approx. 20mm water column through the pipes radially inserted under the bottom of the tank. Inside the tank, the weld cords and the adjacent areas, well cleaned, are covered by brushing with a solution based on phenolphthalein (2.5% phenolphthalein, 27.5% ethyl alcohol, 70% water by weight). In case of leaks, the phenolphthalein solution will be colored locally red. The bed on which the bottom of the tank is placed can be considered as relatively homogeneous (composition, permeability structure), but it cannot be accepted to have oxygen in the central area of the bottom of the tank. Here the material acquires a pronounced anodic character in relation to the peripheral area. In large diameter tanks the effect of the formed macropile is stronger than in those with smaller diameters. In the case of the intensity of the galvanic macropile, the deviations from the flatness of the bottom also act directly. The contact surface of the tank with the foundation is not perfectly smooth. The thermal contractions that result from welding contribute greatly to the deformation of the sheets. When filling the tank, the hydrostatic pressure tends to deform the bottom so that it acquires the shape of the foundation. During this time the air beneath the bottom of the tank is evacuated to the outside. When emptying the situation is reversed. By elastic relaxation of the sheets, the air is accompanied by moisture, possibly even water, under the bottom of the tank. This results in the repeated maintenance of the galvanic macro stack created by the difference in oxygen under the tank bottom.

Calculation of groundbed resistivity. For the calculation of the dispersion resistance of the complex ground beds, the following relation is used [3-9]:

$$\frac{1}{R_p} = \frac{1}{R_{p1}} + \frac{1}{R_{p2}} \tag{1}$$

where

$$R_{p1} = \frac{r_{p1}}{n_1\, u_1} = 0.366\frac{\rho_1}{l}\left(\log\frac{2l}{d} + \frac{1}{2}\log\frac{4h+l}{4h-1}\right)\frac{1}{n_1\, u_1} \tag{2}$$

$$R_{p2} = \frac{r_{p2}}{n_2\, u_2} = 0.366\frac{\rho_2}{l}\,\log\left(\frac{2l^2}{b\,q}\right)\frac{1}{n_2\, u_2} \tag{3}$$

Calculation of dispersion resistance. The dispersion resistance for a vertically mounted sacrificial anode is calculated by the following formula [3-9]:

$$\boldsymbol{R_{pv} = 0.366\,\frac{\rho}{l}\,\log\left(\frac{2l}{d}\right)\sqrt{\frac{4q+3l}{4q+1}}} \tag{4}$$

The dispersion resistance for a number of 5 anodes (one group) is calculated by the formula [3-9]:

$$\boldsymbol{R_{pvg} = \frac{R_{pv}}{u\,n}} \tag{5}$$

3. Internal Cathodic Protection

Although the internal cathodic protection of tanks is considered the most economical if it is taken into account at the design stage, It can, however, be installed at the later stages as an inhabitation measure to the progress of corrosion. To do the internal CP, it is required to define the required mathematics to select and determine the number of anodes. Firstly, surface area to be protected is determined as follows [3-9]:

$$\boldsymbol{S_{Bottom} = \frac{\pi\, D^2}{4}\,[m^2]} \tag{6}$$

*Current calculation required. F*rom the dimensions of the selected tank and cover, the average current demand (I_{cm}), as well as the final demand (I_{cf}) are calculated separately as follows [3-9]:

$$\boldsymbol{I = A_c\, f_c\, i_c} \tag{7}$$

Anode type selection and anode mass dimension. The type of anode is determined on the basis of manufacturing, installation and operation. The dimensions of each anode must be chosen in such a way as to ensure the required current requirement, throughout the projected operating life.

Calculation of anode mass. The total net anodic mass required to support the cathodic protection the entire projected lifetime is calculated according to the following equation [3-9]:

$$\boldsymbol{m = I_{cm}\, t_{dl}\, \frac{2600}{u\, \varepsilon}}. \qquad (8)$$

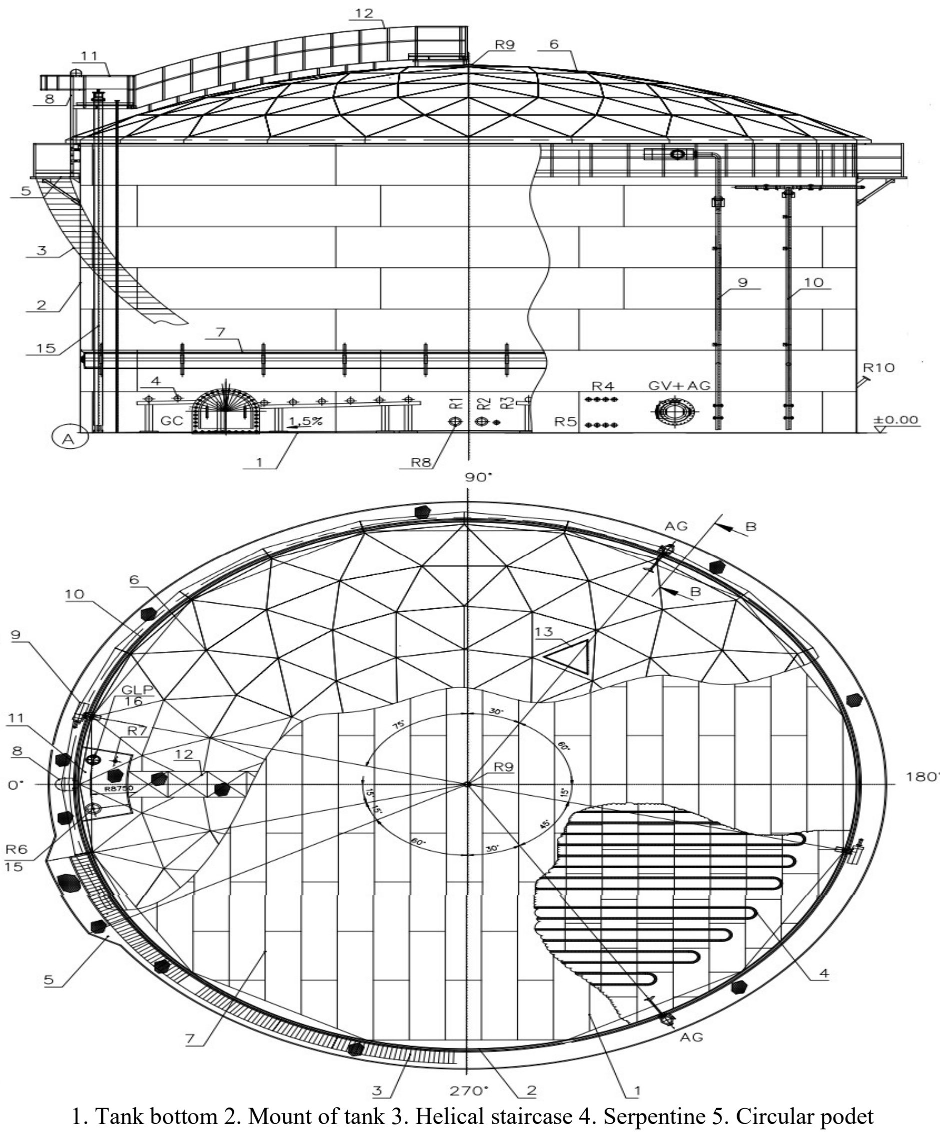
*Calculation of the anodes` number***.** For the type of anode selected, for which the dimensions and their mass are known, the number of anodes necessary for the cathodic protection is determined with the following relation [3-9]:

$$\boldsymbol{m = n\, m_a}. \qquad (9)$$

A limit on the number of anodes is given by the maximum allowable distance between the anodes. Although the relationship is correct, in practice, n and m are in the relationship: $m \le n\, m_a$ due to the mass consumption of each anode. Considering the small space in which the anodes are to be fitted, the number of active anodes of Al-Zn was necessary to ensure the protection of each tank according to its capacity for about 20 years.

4. Field Case Study:Aboveground storage oil tank of 2500 m^3 Capacity

The oil tank of a Romanian processing plant is atmospheric, aboveground, cylindrical type with vertical axis, and it is made of steel sheet, welded construction, self-supporting aluminum geodesic dome cap and full contact aluminum floating membrane as illustrated in Fig. (2). It is equipped with a steam heating coil and a mechanical mixer powered by an electric motor. The tank is equipped with Vega level transmitter, SAAB temperature transmitter and PSI systems according to the established standards. The tank consists of the construction of the access metal constructions such as helical staircase, circular bridge, ladder, and pipe supports (foam and cooling ring) as well. The steel sheets installed on the central panel are made of carbon steel material S235JO. The panels of the peripheral ring are made of carbon steel sheet quality material S235J2. The shell of the oil tank is also made of carbon steel sheet material quality S235J2. The cap of the tank is provided with a tensioning ring and support sliders on the tank. Additionally, it is also equipped with stairs to the center of the dome. Transparent panels (1 + 3 pieces) for natural lighting are provided on the dome. The vents shall be provided with protective nets. The dome complies with API 650 specifications. Aluminum full contact floating inner membrane will meet API 650 specifications. Furthermore, the tank is equipped with automatic acoustic and optical signal system for maximum level and minimum level. The tank is also provided with an electric valve on the inlet pipe and the outlet pipe, which will be actuated automatically at closing and by manual control and by SCADA automation at opening, for maximum level and minimum. Moreover, the



1. Tank bottom 2. Mount of tank 3. Helical staircase 4. Serpentine 5. Circular podet
6. Self-supporting Aluminum geodesic 7. Aluminum floating membrane 8. The access ladder on the dome 9. Foam extinguishing system 10. Water spray system 11. Platform on the dome
12. Access ladder on the dome 13. Light 14. Visit opening 15. Radar pipe
16. GLP pipe 17. Temperature nut.
Fig. 2. Storage oil tank of 2500 m3 under study.

top of the tank is provided with pull / load connection, drain connection, visiting opening (1 piece), cleaning opening (1 piece), aeromechanical foam fittings (2 pieces), coil connections (8 pieces), and temperature connection. The cap of the tank is also provided with opening for taking samples, Vega radar connection, SAAB radar connection, and temperature connection. The aboveground storage oil tank has the following properties:

- Type of construction: welded (bottom, blanket)
- Dome and floating membrane made of Aluminum
- Product stored: crude oil
- Tank capacity: 2500 cubic meters
- Inner diameter: 19.1 meter
- Cap height: 10.5 meter
- Working pressure: atmospheric
- General temperature: min. -210 C, max. + 600C
- Special conditions: non-thermal insulated but with heating coil
- Equipped with fire intervention systems
- Resistivity of the decanted water: 1.5 Ω.m.
- Electrochemical constant zinc (Zn 99.99): 6.98 Kg/A.an, -1030mV
- Electrochemical constant Aluminum / zinc (AlZn 6.5): 4kg/A.an, -1050mV
- Electrochemical efficiency of zinc anodes (maximum yield): 0.89%
- Electrochemical efficiency of aluminum anodes (maximum yield): 0.93%
- Form of anodes: STAS 7335 / 9-88
- Weight of zinc anode: 10 kg
- Aluminum-zinc anode weight: 6.8-7 kg

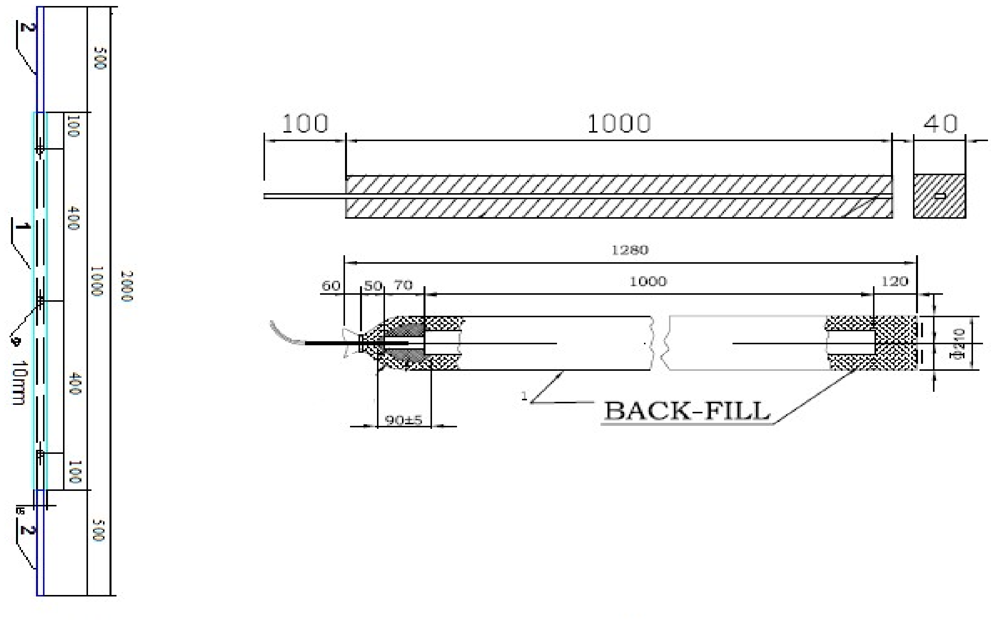
Details of materials, alloys, and their operating conditions, which are previously stated or will see during the whole paper, are presented by companies and institutions' websites [12-24]. Details of the carbon steel materials are discussed and provided [25-26].

Table 1. Selected anodes for external and internal CPS.

Al-Zn anode	Zn anode
▪ Iron (Fe) = 0.12% max.	▪ Copper (Cu) = 0.001% max.
▪ Silicon (Si) = 0.12% max.	▪ Aluminum (Al) = 0.10 – 0.50 %
▪ Copper (Cu) = 0.006% max.	▪ Iron (Fe) = 0.003% max
▪ Zinc (Zn) 5.5 * 6.5%	▪ Cadmium (Cd) = 0.025-0.03%
▪ Indium (In) = 0.01 to 0.02%	▪ Lead (Pb) =0.005% m
▪ Titan (Ti) = 0.025% max.	▪ Other (total) = 0.10% max.
▪ Cadmium (Cd) = 0.002% max.	▪ Zinc (Zn) = rest
▪ Other (each) = 0.02% max.	▪ Potential of Ag / AgCl -1.05+0.05 Volts
▪ Other (total) = 0.05% max.	▪ Maximum Capacity 780 A h / kg
▪ Aluminum (Al) = rest	
▪ Potential of Ag / AgCl -1.05 Volts	
▪ Maximum Capacity 2670 A h / kg	

5. Results and Discussions

The selected anodes for the internal and external cathodic protection of 2500 m^3 tank capacity are 6.5% Al-Zn and Zn anodes respectively. Composition of anodes in aluminum alloy 6.5% Al-Zn and Zn are shown in Table 1. The 6.5% Al-Zn and Zn anodes' sketches are shown in Fig. (3).



(a) (b)

Fig. 3. (a) 6.5% Al-Zn anode, and (b) Zn anode.

Aluminum anode is used as part of a technique called cathodic protection (CP). Aluminum sacrificial anode is also a conductive rod that is attached to metal structures or installed in metal devices. This part is used to reduce corrosion in metal objects, including buildings, structures, and water heaters. With more than 12 years' research history and production experience, there are many researchers and manufacturers for HP and HT aluminum alloys, potential aluminum anodes adopt unique technology and chemical composition. Aluminum anode can be widely applied at high temperature platform area, oil-water separator, heat exchanger, boiler, high temperature pipes, etc. Aluminum sacrificial anodes have several advantages, such as lighter weight and far greater capacity than zinc lamination.

Table 2. Results of the calculation of the land dispersion resistance of a 2500 m^3 tank

No.	Number of groups	Number of anodes included in the group	Resistance of an anode	Resistance of a group	Total tank dispersion resistance
1	**1**	**5**	Rpv =4.95564 Ω	Rpvg = 1.25 Ω.	Rpvg= 0.0089 Ω
2	**2**	**5**	Rpv =4.95564 Ω	Rpvg = 1.25 Ω.	Rpvg= 0.0089 Ω
3	**3**	**5**	Rpv =4.95564 Ω	Rpvg = 1.25 Ω.	Rpvg= 0.0089 Ω
4	**4**	**5**	Rpv =4.95564 Ω	Rpvg = 1.25 Ω.	Rpvg= 0.0089 Ω

Table 3. Results for internal CPS

Protected element	Surface (m2)	Anode resistance (Ω)	Current charged (mA/ anode)	Number of anodes (min. required)	Number of anodes (designed)	System lifetime (years)
Bottom + sleeve (1m)	285.411	0.93936	266.918	15+9=24	24	20.64
Serpentine (Coils)+	105.446	0.93936	226.98	99	99	23.34
TOTAL	455.728	-	-	123	123	-

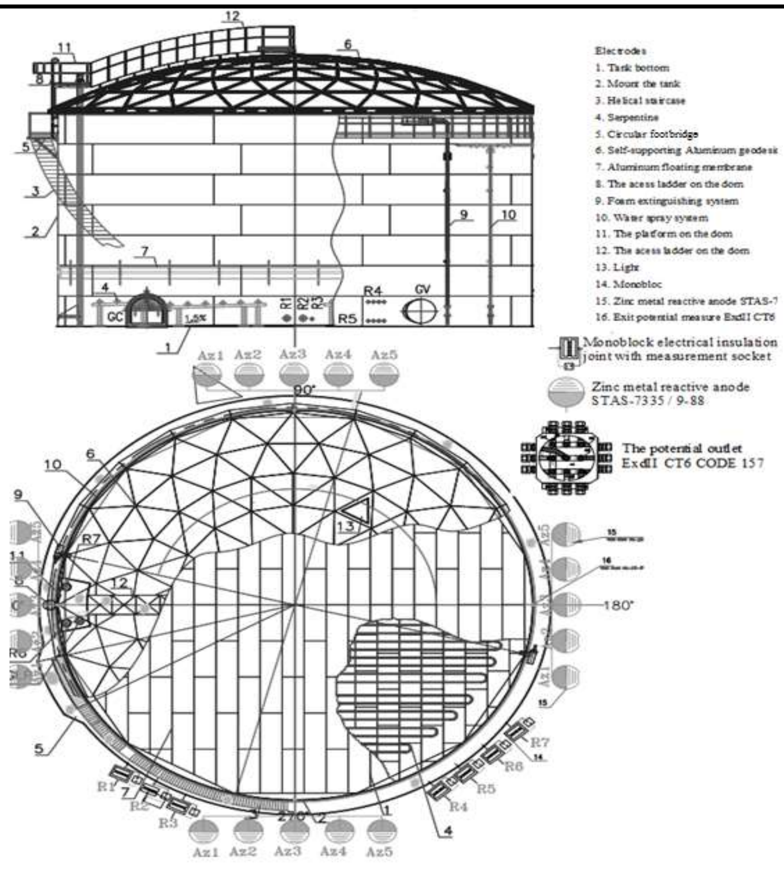


Fig. 4. External CPS anodes distribution.

It is important for external CPS to determine soil analysis corrosion and testing. Soil resistivity provides a valuable information about the corrosion of the material used under and around the storage oil tank. The resistivity around the soil can be used to determine the probability of corrosion on the bottom of the tank. The results of field measurements for soil resistivity can be used to determine the need for cathodic protection. Apply a consistent layer of sand without impurity in order to install a flexible anode through the cable, which is placed near the bottom of the tank. The key fact of the product performance is a central copper conductor covered with a certain polymer. This unique construction allows the current to be passed over long distances through the central conductor, while allowing sufficient cathodic protection for the current to flow continuously through the conductive polymer throughout the anode length. Unlike conventional PC systems, AnodeFlex is placed in the ground in the immediate vicinity of the steel surface, to be protected. There is no dam area above the bottom of the tank and a uniform distribution of protection current is provided throughout the steel surface, thus maintaining potential steel-to-ground "instant-off" potential in the required window of -850mv (-950mv if there is SPC) and -1200mv.

The external CPS with Zn galvanic anodes is selected for the crude oil tank of 2500 m^3 in order to prevent the external corrosion process. The CPS resulted in 20 Zn galvanic anodes which will be divided into 4 groups: each group contains 5 anodes with 4.955 Ω resistance for each anode, the total resistance for each group equals 1.25 Ω, and the total tank dispersion resistance equals 0.0089 Ω as illustrated in Table 2. Moreover, locations and anodes distribution for the external CPS are shown in Fig. (4).

On the other hand, the internal CPS for the oil tank of 455.728 m^2 total surface area to be protected, for the bottom of the tank, sleeves, coils, and supports using Al-Zn galvanic anodes, resulted in 24 anodes of 20.64 years life time for the tank bottom and sleeves. Also, the number of required anodes to protect Serpentine (Coils) and supports is 99 anodes of 23.34 years life time. Each Al-Zn anode has a resistance of 0.9393 Ω. Furthermore, the charged current required for the tank bottom and sleeve anodes is 266.9 mA while 226.98 mA is required for serpentine (Coils) and supports (Table 3). The distribution of Al-Zn galvanic anodes on the interference of the oil tank is shown in Fig. (5). Al-Zn galvanic anodes are welded to the mantle as indicated to galvanic anodes sketches. Al-Zn anodes are welded to the bottom of the tank as indicated after welding to the mantle, the anode rods will be painted the entire length with rubber paint.

In order to investigate the effect of changing the depth of anode place under the tank bottom, a sensitivity analysis study was done using ANODEFLEX 1500 software. The depth of anode under the tank was taken as 0.5, 1.0, and 1.5 meters. It was found that the deeper anode depth is, the longer anode spacing is along the total area of tank bottom.

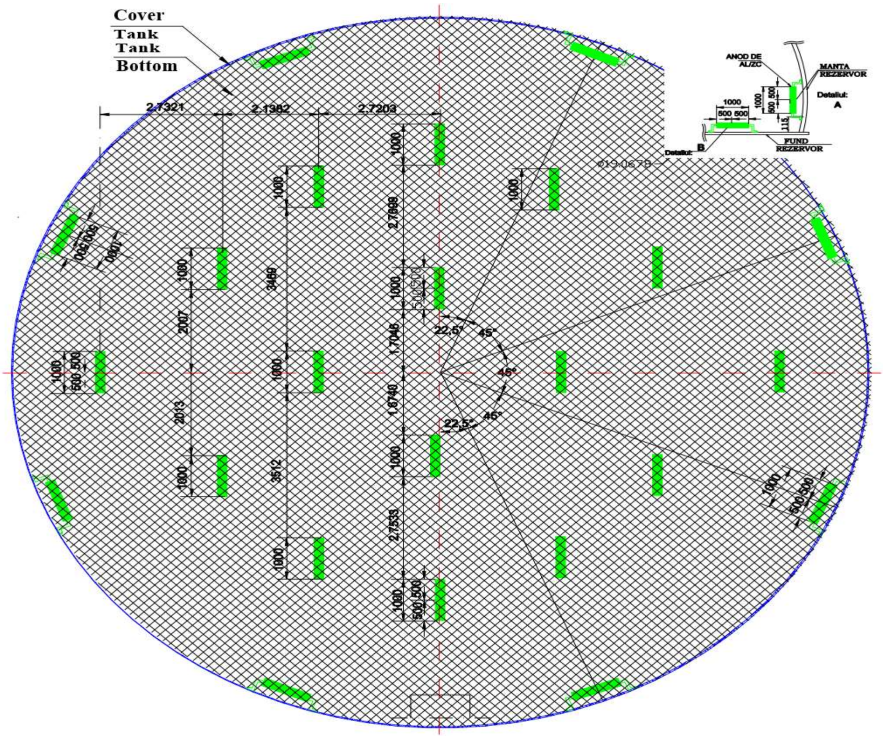


Fig. 5. Internal CPS anodes distribution.

Table 4. The effect of changing anode depth on anode spacing

0.5 m Anode Depth		1 m Anode Depth		1.5 m Anode Depth	
Number of anode sections	**Length of anode section (m)**	**Number of anode sections**	**Length of anode section (m)**	**Number of anode sections**	**Length of anode section (m)**
2	8.63	2	10.97	2	12.94
2	10.72	2	12.65	2	14.38
2	12.35	2	14.04	2	15.6
2	13.7	2	15.23	2	16.67
2	14.84	2	16.26	2	17.61
2	15.83	2	17.16	2	18.44
2	16.69	2	17.95	2	19.18
2	17.44	2	18.65	2	19.84
2	18.11	2	19.27	2	20.24
2	18.69	2	19.82	2	20.93
2	19.19	2	20.29	2	21.38
2	19.63	2	20.71	2	21.77
2	20.01	2	21.06	2	22.11
2	20.32	2	21.36	2	22.4
2	20.58	2	21.61	2	22.63
2	20.79	2	21.8	2	22.83
2	20.94	2	21.95	2	22.96
2	21.04	2	22.05	2	23.05
2	21.09	2	22.09	2	23.09

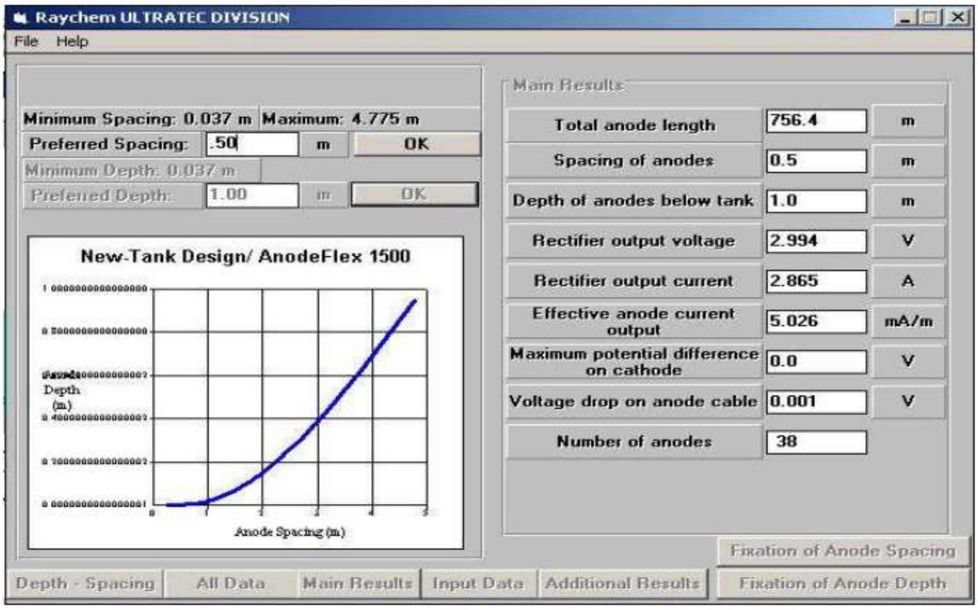


Fig. 6. ANODEXFLEX 1500 results.

6. Conclusions and Recommendation

Based on the above results and analysis, it is extremely important to maintain the integrity of aboveground tanks for both economic and environmental reasons. The Proper design, installation and maintenance of cathodic protection systems can help maintain the integrity and increase the life of storage tanks. For a good protection of the tanks, it is necessary to choose the suitable cathodic protection that is made according to the current requirements and the configuration of the anode. This selection must be made after certain tests such as soil resistivity testing, which it must be implemented in sufficient quantity to help determine the type of cathodic protection (galvanic protection or impressed current) required and the configuration of the anode system. The resistivity can be determined by the method described in ASTM G 57, or by using an equivalent test method. The measurement of resistivity must be obtained in detail to identify possible variations with respect to depth and location. Resistivity data must be obtained from at least two reservoir locations. This soil resistivity helps to determine the corrosion rate of metals in aggressive environments. Cathodic protection is used to control corrosion on the tanks metals that are in contact with an electrolyte. The cathodic protection (grounding) is obtained by groups of anodes, of AL-Zn for internally protection and Zn for externally protection, whose potential prevents the "grounding" of the cathodic protection. The number of grounding groups must comply the condition of correlation between the thickness of the wall, the bottom of the tank and the tank diameter tank. The configurations of buried anodes can be vertical, horizontal and inclined. The anodes can be installed in a certain order under the bottom of the tank. The selection of anode configurations depends on environmental factors, current requirements, size and type of tank bottom to be protected, whether the tank is new or an existing construction, or whether the bottom is single or double.

Nomenclatures

ρ_r= The soil resistivity to the mounting area (the highest value measured for all locations); 37,5Ω.m
A_c= The total area for a tank section, in square meters
b = 0.04 bandwidth
d = 0.065 m-outer diameter of the electrode
D = The diameter of tank, m
D= anode diameter;
f_c = The coverage factor, calculated for the specific conditions
h = q + 1/2 = 0.8 + 3/2 = 2.3, m
i_c = The current density, in amperes per square meter, selected for the specific conditions
I_c= The current demand for a specific tank section, in A;
I_{cm} = The current average demand for current in A;
l = 20 m length of the socket,
l = 2m electrode length,
L= anode length,
m = The total net anodic mass, expressed in kilograms, for the specific tank part;
m_a= The net individual mass of an anode, expressed in kilograms.
n= The number of anodes to be installed on the specific surface section;
n1 = 4 number of vertical electrodes,
n2 = 1 number of horizontal single sockets,
q = 0.8 burial depth
q = 0.8 m - the distance from the top of the electrode to the ground surface
Q= The burial depth of the anode;
R_p = The dispersion resistance of the complex earth socket, in Ω
R_{p1}= The resistance of the vertical groundbed, in Ω = ρ1 = 25.72 Ωm at 3 meters depth
R_{p2}= The resistance of the horizontal groundbed, in Ω = ρ2 = 23.60 Ω m at 1 meter depth.
R_{pv}= The dispersion resistance for a vertical anode;
R_{pv}= The dispersion resistance for an anode mounted vertically;
R_{pvg}= The dispersion resistance for a group of anodes;
t_{dl} = The lifetime of the projected life, in years;
u = The usage factor
U= The correction coefficient (0.8 for anode mounted vertically);
u1 = 0.82 coefficient of use,
u2 = 0.80 coefficient of use,
ε = the electrochemical capacity of the anode material, in ampere hours per kilogram;

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