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Design of Sacrificial Cathodic Protection System for Crude Oil Pipeline (Part-1 Theoretical Aspects)

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ABSTRACT

Cathodic protection (CP) is a technology used for controlling corrosion by making a metal surface the cathodic side of an electrochemical cell. This paper discusses the methods for designing sacrificial cathodic protection and applies this method to evaluate two case studies of cathodic protection. In the first case, there is a pipe constructed from API 5L-X70 steel, with a diameter of 1 m and a length of 6 m, extending over a distance of 100 m. In the second case, a pipe made from API 5L-X60 steel has a diameter of 0.50 m and a length of 8 m, extending for a distance of 450 m. The findings indicated that as the diameter, length, and extension of the pipe increase, the required corrosion protection current also rises. Consequently, the number of sacrificial anodes required for cathodic protection and associated costs also increases. Furthermore, the study revealed an inverse relationship between sacrificial electrode current and electrode lifespan; as the electrode current increases, the lifespan of the electrode decreases, necessitating periodic replacement of the electrode.

INTRODUCTION

A crude oil pipeline consists of a network of steel, typically buried, that effectively conveys substantial quantities of unrefined oil from production locations (wells) to storage, processing plants, and refineries. Corrosion of underground pipelines presents a significant challenge, encompassing various types, such as uniform, pitting, and microbially induced corrosion. This phenomenon is influenced by soil characteristics, moisture levels, and stray currents, which can lead to leaks, failures, and harmful environmental impacts. The corrosion processed in underground pipelines generates electrochemical cells, where the pipeline serves as an anode and consequently loses metal. To mitigate this issue, cathodic protection (CP) is employed, which converts the entire pipeline into a cathode. This can be achieved by connecting the pipeline to a more reactive “sacrificial anode” (such as magnesium or zinc) that will corrode in place of the pipeline, or by implementing an impressed current system that applies current to the pipeline, thereby safeguarding it and significantly prolonging its operational lifespan (Essam, 2022).

A sacrificial anode cathodic protection system safeguards metal structures against corrosion by linking them to a more reactive (less noble) metal, such as zinc, aluminium, or magnesium. This metal corrodes (sacrifices itself) in place of the structure, utilizing galvanic action to provide electrons and convert the structure into a cathode. This method does not require external power and delivers straightforward, low-maintenance protection for pipelines (Marshall & Edwad, 1988).

LITERATURE REVIEW

Numerous reports highlight issues affecting the performance of cathodic protection systems. Amh *et al.* (2017) reviewed design approaches for both sacrificial and impressed cathodic protection systems, providing a list of relevant design equations. Hamed *et al.* (2020) showed that cathodic protection (CP) method is widely used in the oil and gas industry in order to reduce rust and corrosion of structures and metal pipelines and their associated cost. They proposed a new model to design a cathodic protection system for oil and gas transmission pipelines. Meanwhile, Dai *et al.* (2023) employed combined mathematical and electrochemical models to explore pitting corrosion in pipeline steel X100 under cathodic protection potential. Their findings indicated that the development of an amorphous corrosion product layer reduces the number of localized anodic corrosion sites and decreases the density of pitting.

In this paper, approaches of design cathodic protection by sacrificial anodes is explained and given in detail. This approach is applied in evaluations of two cases of crude oil pipeline have different diameter and length in different soil resistance for compared.

MATERIALS AND METHODS

Thirteen steps are required when designing sacrificial cathodic protection systems. Table 1 presents the steps and equations utilized in the design methodology of the sacrificial cathodic protection technique for pipes. (Ezekiel, 2015, DNV, 1993, and Mainier, 2014). The

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definition of symboles of equations in table 1 is given as follows:

D_o : Outside diameter of pipe (m).

L_o : Pipe length (m).

$I_{protect}$: Current required to protection (mA).

I_{des} : Design current density (mA).

CE: Coating efficiency %.

AS: Pipe protected surface area (m²).

ρ : Soil resistivity in (ohm-cm).

IA: Current output from anode.

N: Number of galvanic anodes based on required current.

Y: Calculated design life for anode (year).

UF: Utilization factor

CNT: Consumption rate of Mg anode.

Ab: Total area of pipe to be protected (m²).

S: Distance between one anode and another in outer surface of pipe.

La: Anode length (m).

Da: Anode diameter (including the backfill) (m).

h : Depth from surface to center of the anode (m).

CRbase: The soil's corrosion rate.

Eff: The effectiveness of corrosion protection.

Table 1: Lists the approaches used in pipeline sacrificial cathodic protection.

1	Pipeline Area to be Protected (m ²)	$As = \pi D_o L$
2	Design current density (A/m ²)	Chosen according to type of environment
3	Current required to protection	$I_{nprotect} = (I_{des}) * surface\ area * (1 - \%CE)$
4	Chosen Single anode, this chosen by designer person	Anode chosen from manufacture company has weight W_a , length L_a and diameter d_a
5	The anode to electrolyte resistance (Ra)	for single rode or (slender anodes) is placed from Vertical Anode: $Ra = \rho / 2\pi L (\ln 8L/d - 1)$ For a single horizontal anode. $Ra = 0.00521\rho / La (2.303\log(4La)/d + 2.303\log La/h + 2h/L - 2)$
6	ΔE for Mg anodes have a driving potential	0.7 min or 0.9 max v
7	Calculate current output from anode.	$I_A = \Delta E / Ra$
8	Number of galvanic anodes based on required current	$N = I_{nprotect} / I_A$
9	Calculated design life of anode, in year	$Y = (UF * capacity * wa * E) / I_A$
10	Calculate the total weight of anodes used	total weight of anodes = $(CNT * Y * I_{nprotect}) / (utilization\ factor * eff.\%)$
11	Calculate the quantity of anodes to meet the design life years based on anodes weight	$NL = (totl\ weight\ of\ anodes) / (weight\ of\ single\ anode)$
12	Protect area by one anode	$A_{nprotect} = As / N$
13	Distance between one anode and another in outer surface of pipe	$S = L / N$

CPE: Cathodic Protection Effectiveness %.

External corrosion is a stealthy predator, slowly devouring pipeline walls from the outside in, stripping away material, and reducing the wall thickness (Scott, 2015).

$$\text{Corrosion Rate} = (1 - \text{Eff}) * \text{CRbase} \quad (1)$$

CRbase is the soil's corrosion rate influenced by environmental factors like moisture content and soil resistivity. The effectiveness of corrosion protection measures, denoted as Eff, is calculated using:

$$\text{Eff} = (1 - \text{CPE}) \times (1 - \text{COPT}) \quad (2)$$

CPE is cathodic protection effectiveness, for soil having resistance in range (1000 to 5000) ohm.cm, the cathodic protection Effectiveness is 55% and COPT is the coating protection effectiveness which is equal to 25%. The soil corrosively is 0.2 mm/y.

Soil Resistivity Measured

The two-electrode soil box method is predicated on

measuring the resistance between two electrodes located on opposing faces of a soil box containing a soil sample. Figure 1 shows H-4386SM Soil Box, 280 ml capacity and size (222 * 38 * 32) mm. A voltage is impressed between the two opposite face electrodes, causing current to flow, and the voltage drop between them is measured. Ohm's law reveals the resistance.

Procure enough Pour or tamp soil sample to be tested into soil box until flush with top of box. Where soil or similar material is to be tested, the two brass potential pins should be temporarily removed to facilitate filling the box. Material should be tamped down until compacted to same degree as soil at test site. Connect power supply and DC milliammeter so as to pass current between the two end terminals of the soil box. Connect DC Electronic Voltmeter between the two brass potential pins, which are located near the center of the soil box. Using appropriate Milliammeter and Voltmeter ranges, measure the potential between the two brass pins with no current applied and



Figure 1: H-4386SM Soil Box

again with measured current passed between the end terminals of the soil box. The method used according to ASTM G57, G187 [9].

$$R = (\text{change in voltage (mV)}) / (\text{current (mA)}) \quad (3)$$

RESULTS AND DISCUSSION

Two scenarios are examined regarding the sacrificial cathode utilizing a Magnesium anode produced by Zhejiang YUXI Corrosion Control Corporation in China.

The magnesium anode is circular in shape and possesses the following specifications: type YX-MG-R100, weight of 10 kg, diameter of 14 mm, and a length of 570 mm. The characteristics and properties of the pipes analysed for the two cases under study are presented in Table 2. The soil resistivity is directly measured using the 4-probe tester box method in the laboratory, with the results displayed in Tables 2 and 3, respectively. Sacrificial anode cathodic protection current demands of

Table 2: Pipeline’s specifications for first studying case

Pipe outside diameter	1m made from API 5L-X70 steel pipeline
The pipeline length	600 cm (6 m) for total distance of 1000 m
Wall thickness	0.6 cm (0.006 m) or (6 mm)
Current density assumed	10 mA/m ²
Soil resistivity (measured)	1020 ohm.cm

Table 3: Pipeline’s specifications for second studying case

buried Pipe outside diameter	0.50 m diameter made from API 5L-X60 steel pipeline
The pipeline length	800 cm (8 m) for total distance 450 m
Wall thickness	0.5 cm (0.005 m) or (5 mm)
Current density assumed	9 mA/m ²
Soil resistivity (measured)	1300 ohm.cm

Table 4: Results of calculation for two studying cases

Quantity calculated	The First Case	The Second Case
As	3142 m ²	706.86 m ²
design current densirty	10 mA/m ²	9 mA/m ²
I _{nprotect}	1.414*10 ⁴ mA	2863 mA
Ra	13.36 ohm	13.36 ohm
Total voltage	0.9 max v	0.9 max v
I _A	0.067 A	0.052 A
N	209.9 say 210	55.26 say 56
Y=	15.77 year	20.51
total weight of anodes	8349 kg	2198 kg
NL	834.8 say 835	219.7 say 220
A _{nprotect}	14.966. m ²	12.79 m ²
S	4.78 m	8.14 m

the API 5L-X70 steel pipeline with 1m diameter and 6 m length, and a buried pipe has 0.50 m diameter made from API 5L-X60 and 8m length have been computed according to approaches and equations listed in Table 1. The results of calculated are listed in Table 4.

The sacrificial anode direct current demands were calculated as 14410 mA and 2863 mA for two cases respectively based on coating deficiency 0.55. Increase pipe diameter and length increases the current required to protect from corrosion and then increases the number of anodes needs to use in cathodic protection. The current protection effect directly in anode life and as current protection increases leads to decrease the anode life and needs to replace during service used. As seen from table 3, that the anode life of first case is 15.77 year, while that for second case is 20.51 year respectively.

In other hand, soil resistivity play important role in cathodic protection and effect directly in anode current provide. As given in Table 2 that case 1 has soil resistivity is 1000ohm.cm , while that in case 2 is 1300 ohm.cm, but current output from same metal and characteristics anode used for both cases is 0.067 A and 0.052A respectively.

The overall Effectiveness calculated by use of Eq.2 which is equal to 33.75% and model external corrosion rate is 0.1325 mm/y. the corrosion rate obtained from the model can be used to calculate the remaining life of pipeline segments.

CONCLUSIONS

The preceding discussion indicates that an increase in pipe diameter and length results in a higher current requirement for corrosion protection, subsequently leading to an increased number of anodes needed for cathodic protection. The design calculation for cathodic protection of the sacrificial anode intended for the API 5L-X70 steel pipeline, which is to be installed in soil, indicated that a total current demand of 14410 mA is necessary to protect the pipeline, while the current requirement for the API 5L-X60 X70 steel pipeline is 2863 mA. The current protective directly impacts the lifespan of the anode, and as the current protection increases, it results in a reduction of the anode's lifespan, necessitating replacement during its service life.

REFERENCES

- Ameh, E. S., & Sunday, C. I. (2017). Pipelines cathodic protection design methodologies for impressed current and sacrificial anode systems. *Nigerian Journal of Technology (NIJOTECH)*, 36(4), 1072 – 1077.
- ASTM G187-23, (2023). *Standard test method for measurement of soil resistivity using the two-electrode soil box method*, ASTM International Report, USA.
- Dai, M., Frank C. Y., Zhen, W., Feng, H., & Qian, H. J. (2023). Understanding pit initiation of pipeline steel X100 under cathodic protection potential fluctuating with various duty cycles, *Corrosion Communications*, 12, 11–18. <https://doi.org/10.1016/j.corcom.2023.02.001>
- David, E., Daniel T., & Victor, E. O. (1993). DNV-1993 Cathodic Protection Design, Recommended Practice RP, DVN Corporate Headquarter, Oslo, Norway.
- Essam, M. S., Mohamed, A. M., Abdel, S. H. & Mostafa, A. G. (2022). Cathodic protection performance improvement of metallic pipelines based on different dc compensation methods, *Electric Power Systems Research*, 210, 1-20. <https://doi.org/10.1016/j.eprsr.2022.108064>
- Ezekiel, E. (2015). Introduction to electrical design or cathodic protection systems, Ezekiel Enterprises, LLC, article's Review, 2015.
- Hamed, M. O., Mahdi, A., Ali, K., & Mehdi, E. (2020). Design and analysis of the cathodic protection system of oil and gas pipelines, using distributed equivalent circuit model, *Journal of Natural Gas Science and Engineering*, 84, 1-23.
- Mainier, F. B., Leta, F. R. & Feliciano, F. F. (2014). Application of anti-corrosive techniques compatible with the environment to engineering education, *American Journal of Environmental Engineering*, 4, 176-181. <https://doi:10.5923/j.ajee.20140406.06>
- Marshall, P., & Edward, G. P. (1988). *Pipeline corrosion and cathodic protection: A Practical Manual for Corrosion Engineers, technicians, and field personnel*, 3rd Edition, Publisher by Gulf Pub. Co., USA.
- Scott, D. (2015). External corrosion: corrosion modeling for pipeline integrity, Report of Cenosco Croatia D.o.o. Corporation.