

Sacrificial Anode Cathodic Protection of an Underground Natural Gas Pipeline Using COMSOL Multiphysics

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Abstract

Corrosion occurs typically when cathodic protection coating, or other preventative method failed or corroded. In this research, using corrosion and structural modules in COMSOL Multiphysics, the model was created using finite element method. The preventative approach was taken by application of Sacrificial Anode Cathodic Protection to pipeline surface by using magnesium anode to protect the cast carbon steel pipeline under various soil types and analyze the safety potential and evaluations were made.

Keywords

External Corrosion, Failure, Natural Gas Pipeline, Structural Health Monitoring.

1. Introduction

Because of the increasing growth of the oil and gas industry, the operational and management complexity of pipelines has expanded dramatically. Corrosion difficulties and catastrophic consequences on pipelines are frequently caused by extreme operating conditions and a hostile environment. Corrosion in underground natural gas and liquid petroleum pipeline takes many forms and needs specific mitigating strategies to manage and detect corrosion.

Pipelines are now the most essential mode of transportation, and these will be the best tool for energy transmission for the next 50 years as studied for the petrochemical, oil, and gas industries. Long-distance gas pressure measurements are taken by high-pressure stations. Gas pipelines serve a significant and vital role; consequently, they must be safe. However, the use of earliest operation of pipelines rises the possibility of existence. Interior and exterior corrosion is the mostly the cause of these incidents, which are particularly active in degrading pipes carrying gas, reducing wellbeing. As a result, regulating deterioration in gas pipelines requires the employment of cathodic protection. The deterioration rate is reduced by this system which has cathodic potential and turns into cathode. Pigging, also known as examinations of pipeline, are required on a regular basis. The movement of product to accomplish detailed obligations within the pipeline is called a pig. First, as one of the most serious hazards to gas pipelines, corrosion and its various forms will be addressed in this study (Karami 2012). There are various ways justifying corrosion, with the most important is the cathodic protection. Lastly, pigs will be researched for the reason that pipeline functioning requires nonstop reviews for security reasons.

Most pipeline undergoes different types of corrosion. In order to reduce these corrosion related problems, the principle of cathodic protection was used to lower the corrosion potential, making it invulnerable and regulates the rate of corrosion of a metallic structure. This can be accomplished by using two types of cathodic protection either Sacrificial Anode Cathodic Protection/Galvanic Anode Cathodic Protection. This project uses Sacrificial Anode Cathodic Protection System.

It works by placing an anodes of magnesium alloy in a clay soil electrolyte to create circuit. The deterioration is controlled by the movement of current from anode into the electrolyte and release onto the steel pipeline to be protected. The cathodic protection is modelled in COMSOL Multiphysics software.

Multiple anodes are buried along horizontal pipeline to reduce surface area, decrease electrical resistance to the ground and extend the life of anode.

The impressed current cathodic protection uses the power from external source with inactive anodes whereas, sacrificial anodes cathodic protection uses the naturally occurring electrochemical potential difference between

dissimilar metallic elements for pipeline and the magnesium alloy anode connected by copper wires to provide protection.

Aluminum alloy are used for cathodic protection in environment containing chloride ions, because in soil and fresh water aluminum passivates. According to the research (Mahasiripan et al. 2011). for a month the hot-rolled steel grade SS400 was combined with magnesium and the aluminum sacrificial anode in artificial and actual seawater. The results show that aluminum sacrificial anode is more effective than magnesium sacrificial anode due to aluminum anode can reduce steel corrosion rate than magnesium.

Chemically, magnesium is resistance to oxidation due to the thin layer of oxide covered its surface which prevents it from exposed to air. This is because it is extremely appropriate for sacrificial anode usages to reduce the effects and vulnerability to deterioration of exteriors of other metals. Sacrificial anode is the oldest type of cathodic protection system whereas impressed current is currently widely used in oil and gas industries.

2. Methodology

2.1 Mathematical Model

In this section, prototype model of a pipeline is initially created in a modeling finite element software, COMSOL Multiphysics 5.4. Figure 1 depicts the general geometry used in the numerical investigation. It demonstrates that the model is made up of a gas pipeline surrounded by earth. Thus, soil domain's electrolyte conductivity for clay loam is considered to be 0.0246 S/m (40.6-ohm meter).

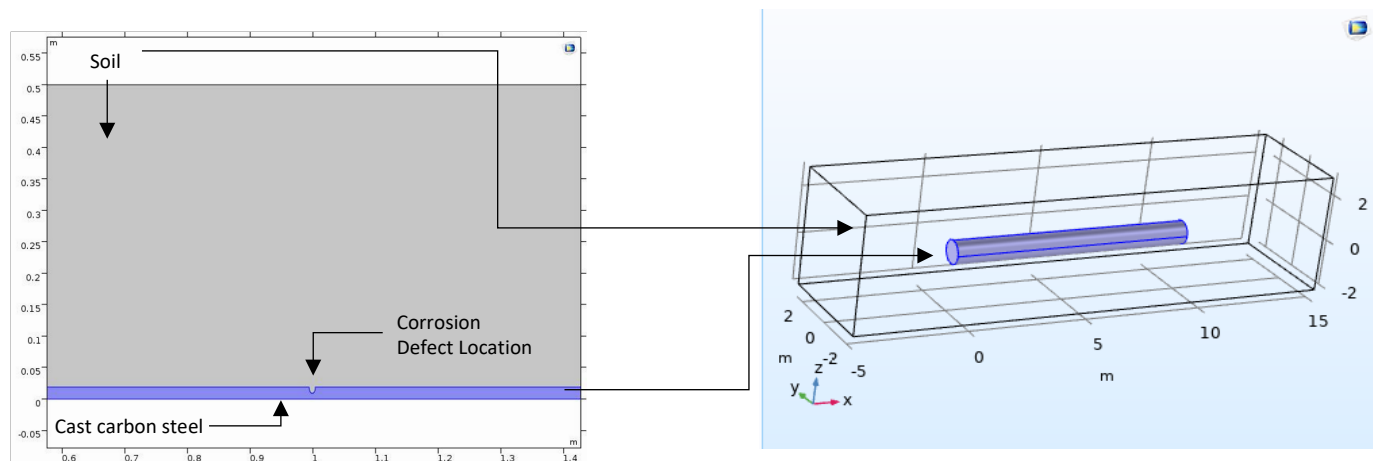


Figure 1. The model under study consist of a steel pipeline with a corrosion defect and surrounding soil.

The pipeline is composed of cast carbon steel, and the material specifications of pipeline measures length of 20 m and wall thickness of 0.02 m and 1m diameter. As illustrated in Figure 2-3, the corrosion defect on the pipeline's outside has an oval shape with a variable length and depth.

The defect depth is the distance from surface of the pipe in vertical direction to the deepest point that corrosion defect reached whereas, the defect length of defect is the distance from the surface of the pipe in one end the of the crack in the horizontal direction to the other end reach by the corrosion defect.

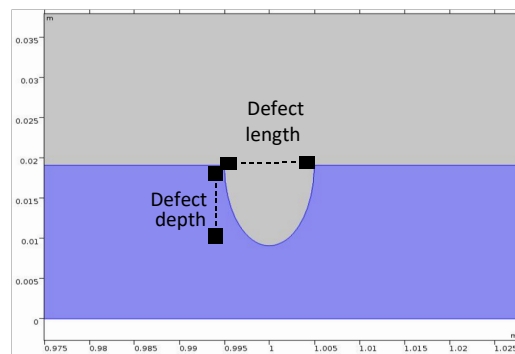


Figure 2. The corrosion defect has an elliptical shape with a variable length and dept.

2.2 Soil

Table 1. Soil's resistivity of various soil types in Ohm-centimeters.

Soil Types	MINIMUM	AVERAGE	MAXIMUM
Ashes, cinders, brine, waste	590	2,370	7,000
Clay, shale, gumbo, loam	340	4,060	16,300
Same, with varying proportions of sand and gravel	1020	15,800	135,000
Gravel, sand, stones with clay or loam	59,000	94,000	458,000

Soil resistivity is the valuable input. Protective action is to be taken due to, lower the resistivity of the soil the higher the activity of corrosion (Table 1). The soil's resistivity differs extensively throughout the world and varies seasonally with moisture content, mineral and dissolves salts. Rocky soil or gravel has high resistivity (Figure 4-6).

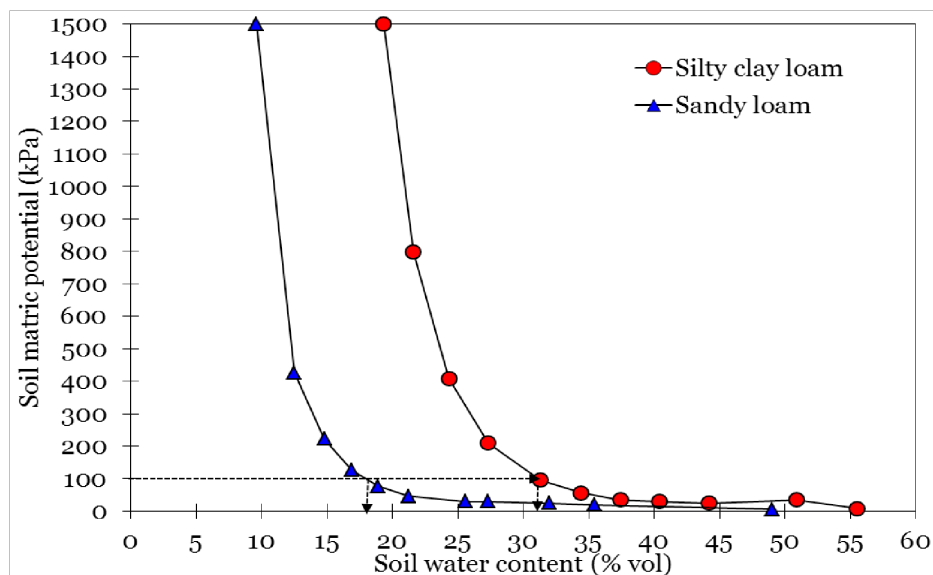


Figure 4. Silty clay loam and sandy loam soils retention curve for soil-water (Chalgham et al. 2019, Dd 800)

2.3 Anode Types

Table 2. Approximate voltage difference for iron and steel of different types of anodes in soil or water.

Type of Anode	Typical Anode Open Circuit potential (V _{SCE})	Conservative Driving Voltage Between Anode and Protected Iron Steel (V)
High potential magnesium	1.75	0.85
Standard potential magnesium	1.55	0.65
Zinc	1.10	0.20

According to this study, the best indicator for potential for corrosion in moist to saturated conditions. The range of resistivity defines the relative effect of soil resistivity (Table 2). With over 4,000 ohm-cm soil has little or even no effect on zinc-coated with life expectancy over 30 years. With the range of 4,000 ohm-cm soil to 2,500 ohm-cm soils zinc-coated will last 25 years or longer. Also, with 2,500 ohm-cm to 1,500 ohm-cm soils, zinc-coated will last for 20 to 25 years life expectancy. This clearly indicated that the resistivity of the soil decreases, the lifespan of the pipeline coated with zinc also reduces due the better soils electrolyte conductivity which increases the rate of corrosion. Soils below 1,500 ohm-cm is very corrosive. Therefore, additional coating or anodes is required to assure a life beyond 5 or 10 year of pipe coated with zinc. Magnesium anode installed at the time of construction to the extended life beyond 20 to 25 years. The anodes at the sacrificial anode cathodic pretention system must be regularly inspected and replaced when consumed.

From the above information the required parameters are obtained for corrosion simulation and application of sacrificial anode cathodic protection on underground natural gas pipeline by COMSOL Multiphysics software was modelled and simulated with physics based Solid Mechanics and Secondary Current Distribution Interface.

3. Sacrificial Anode Cathodic Protection

3.1 SACP mechanism

The two different metal which are positioned in contact with each other in the electrolyte. One is the anode and the other is the cathode, and when the metallic path is supplied to the circuit, current flows. The mechanisms of SACP system is similar to the reaction mechanism of electrochemical cells. In sacrificial anode the protected metal is placed at the cathode side and then a more reactive metal or alloy is placed at the anode, which has larger potential difference and connected to the metal. So, the redox reaction proceeds simultaneously at the anode which means sacrificial metal will be consumed. On the other hand, reduction occurs on the cathodic side preventing the protected metal form corroding. Lead wires are normally used to facilitate the connection to the structure being protected. The lead wires may be attached to the structure by either welding or mechanical connections (Meagher et al. 2008, Irmak 2015, Handbook 1979, Guyer et al. 2014).

The material used for sacrificial anode are pure active metals such as aluminum or zinc or are magnesium or aluminum alloys that have been specifically develop to be used as sacrificial anodes. The advantage of using this preventative method is, it can be used where there is no power, low initial cost, less supervision required and simple installation and additional anodes can be added if the initial installation proved to be inadequate (Figure 5).

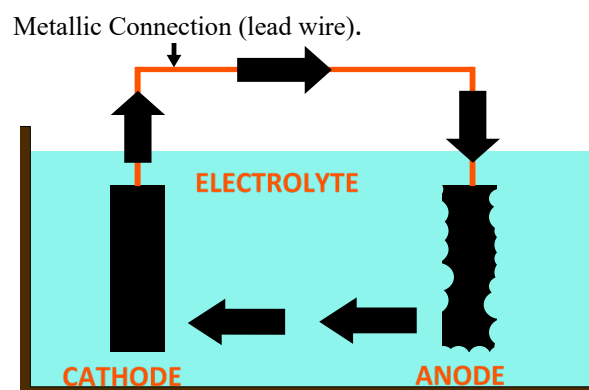
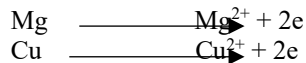


Figure 5. SACP mechanism

3.2 Anode reactions

One or more electrons is given out by the metal atoms and become metal ions. It is represented by the chemical equation below.



3.3 Cathode reactions

The first thing to know is steel alloy is an iron alloy which contains mostly iron and smaller chromium and other alloy elements. Therefore, the chemical equation is shown below.



3.4 Software modelling and simulation

COMSOL Multiphysics software is used in this simulation of underground natural gas pipelines.

The physics called secondary current distribution is used and study called stationary is selected.

From the geometry section, pipeline of 0.5 m radius and height 20 m, the soil electrolyte with a block width 30 m, 10 m depth and 10 m height containing the carbon steel pipeline are drawn. The pipeline is buried 2 m below the soil electrolyte. The magnesium alloy anode with 0.2 m radius and 1m length at the center of the pipeline are drawn and placed 1.5m away from the pipeline (Figure 6).

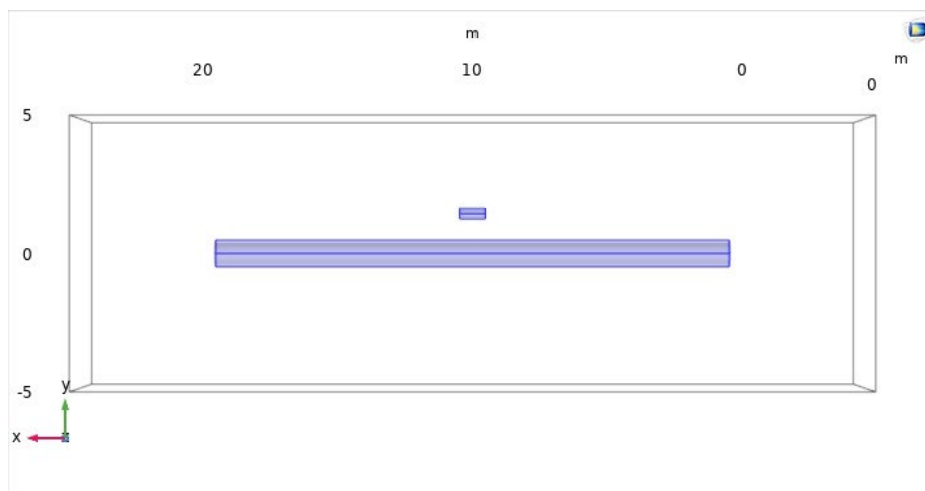


Figure 6. One magnesium anode with pipeline buried in the soil.

The difference between is taken between electrolyte with pipeline and the anode. The material clay loam is assigned to the electrolyte. Soil electrolyte conductivity of 0.025 S/m (40.6 ohm-m) is used. The soil resistivity is the reciprocal of soil conductivity on the model.

Then electrode surface is selected and defined as pipeline, anode and electrolyte in the corrosion cell.

- Anode electrode is defined and equilibrium potential of -1.75V of high potential magnesium anode is assigned.
- Another electrode is defined which is the pipeline and electrolyte current density of -0.020 A/m²(20mA/m²) applicable for buried pipeline is used. The external electric potential that is anode to pipeline connection is 0V which is very low resistance.

Then the mesh is created and the study is compute. After the computing, the results of electrolyte potential, electrolyte current density and electrode potential vs adjacent reference are shown.

Last but not the least, the pipe to soil potential profile is created. From the results menu, the 3D plot is created and selected the surface. Negative (-Phil) is included in the expression to show all values negative. From the surface 1, the selection is created. The pipeline surface along with anode is selected to see how potential profile looks like.

After the study is computed, it is seen that pipeline is not protected well. Therefore,

- Increase the number of anodes to four (4) by selecting the array in geometry enter No:4 in size x displacement of 5m between each other.
- Compute the electric current density.

It can be seen that the 20m pipeline is well protected.
Another simulation was taken when using different soil's resistivity or soils electrolyte conductivity (Figure 7).

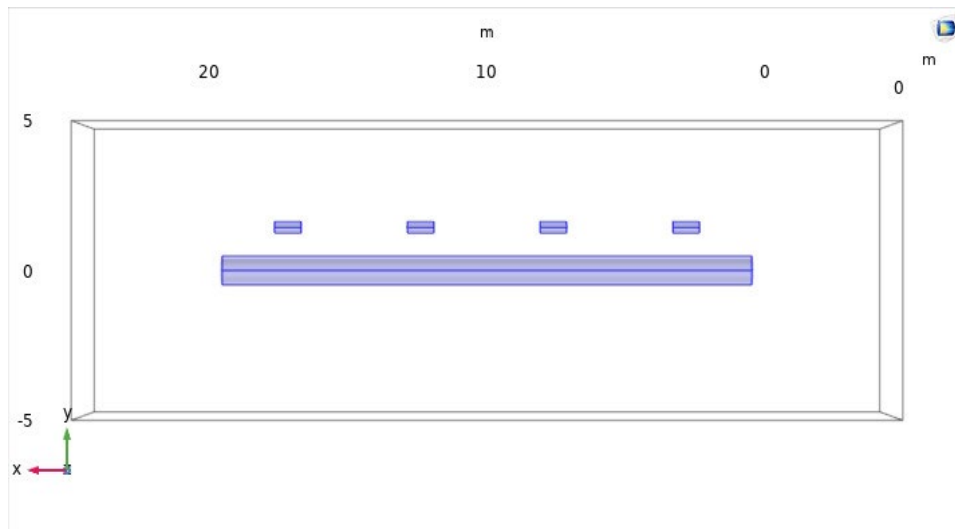
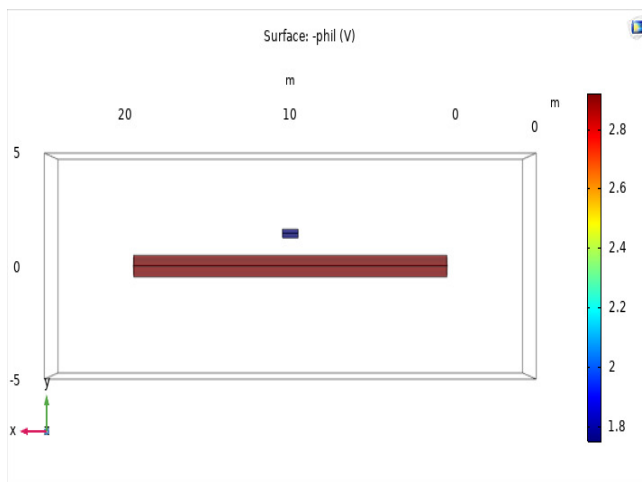


Figure 7. Four magnesium anodes buried alongside the pipeline in the soil.

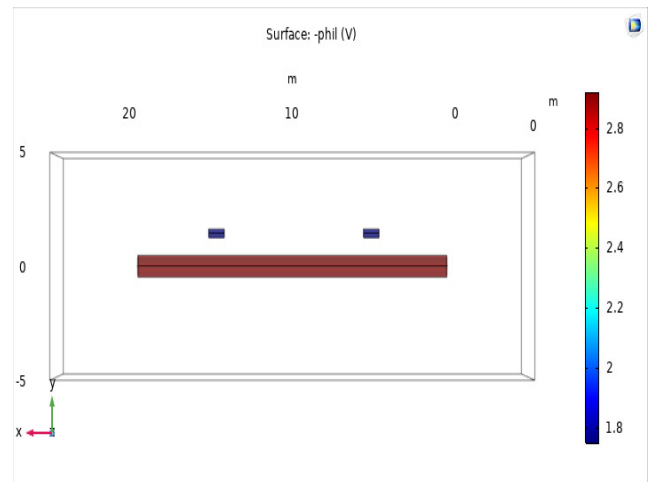
4. Results And Discussion

4.1 Sacrificial Anode Cathodic Protection model

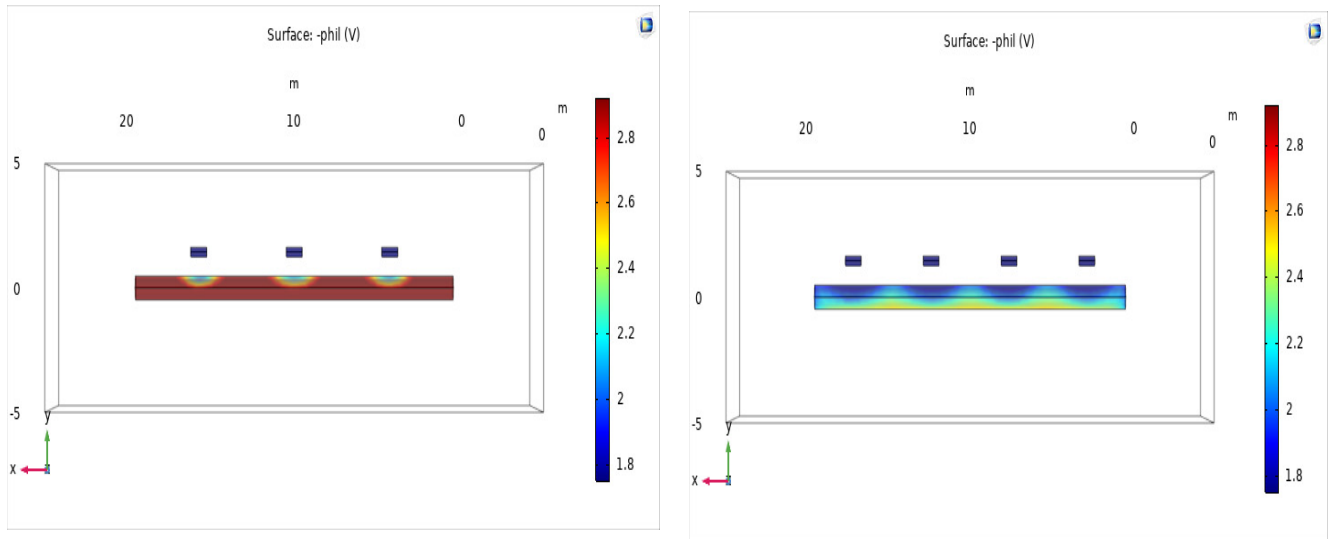
Increasing number of anode while keeping resistivity constant at $70\Omega\text{-m}$ (Figure 8-9).



a)



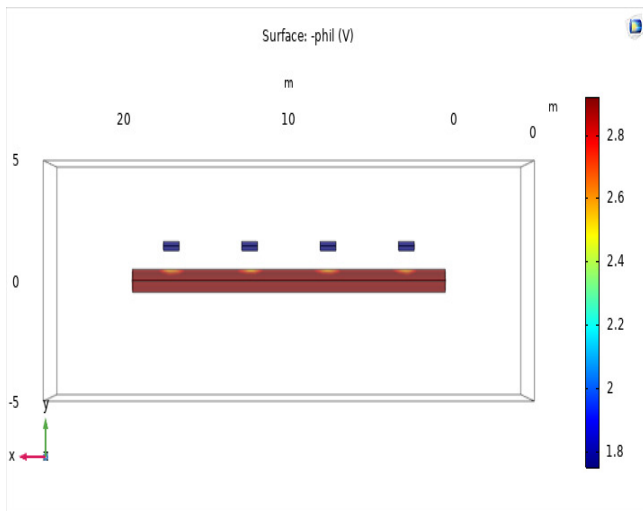
b)



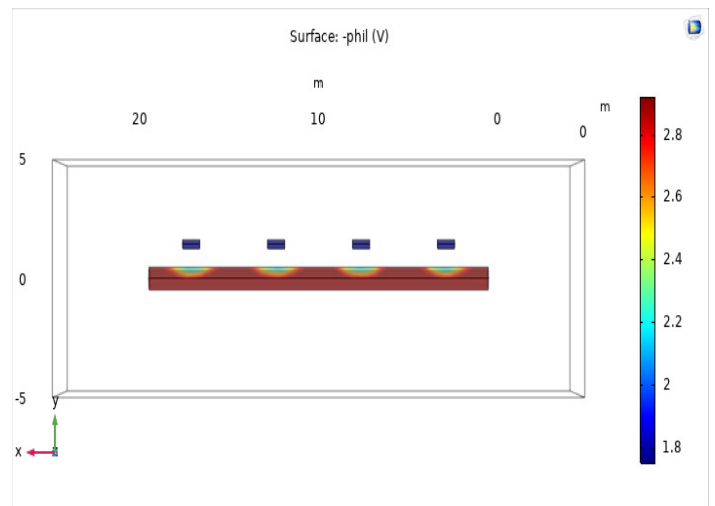
c)

d)

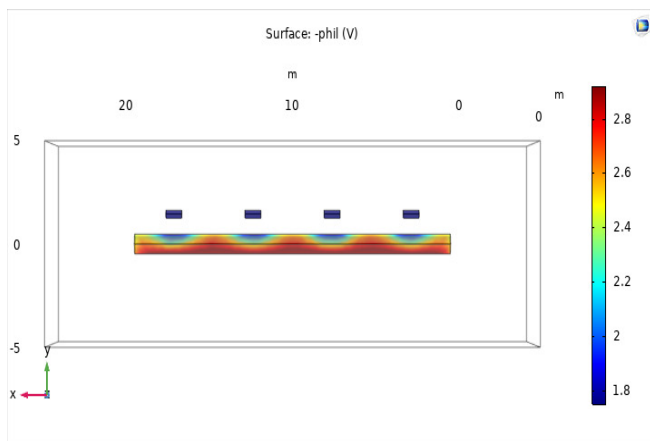
Figure 8. Pipe corrosion potential when increasing number of anodes with constant resistivity.
Decreasing resistivity to 70 Ω -m while keeping the number of anode constant.



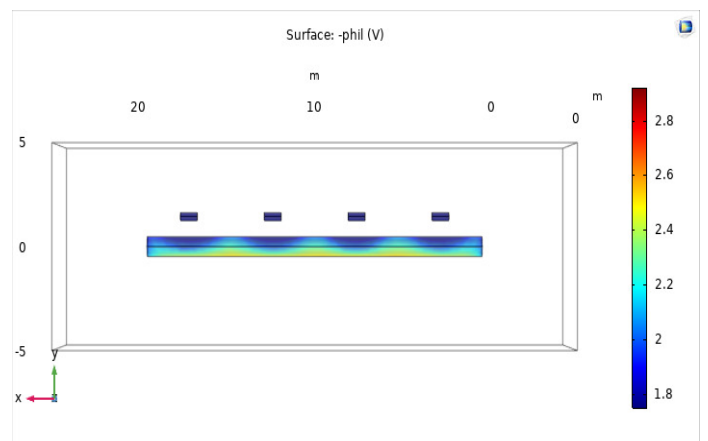
a)



b)



c)



d)

Figure 9. Pipe cathodic protection potential under various soil electrolyte resistivities: a) 100Ω-m, b) 90Ω-m, c) 80Ω-m, d) 70Ω-m

From the Sacrificial Anode Cathodic Protection model, it shows that one anode cannot polarized the pipeline in order to protect it cathodically at constant soil resistivity. Therefore, increasing the number of anodes shows that the pipeline is well protected. Also increasing the distance of the anode away from the pipeline shows that it is not well protected than placing them closer.

Decreasing the resistivity while keeping the number of anodes constant shows that pipeline is well protected. Therefore, the pipeline of 20 m can be well protected when using the magnesium alloy anode with 0.2 m radius and 1m length, and placed at a distance of 1.5 m away from the pipeline under the electrolyte resistivity of less than 70Ω-m. Therefore, SACP can be best used any soil less than 70 ohm.m soil which is a good electrolyte conductivity. See Table 3 of best soil types where this preventative method can be best used.

5. Conclusion

Finally, this research offered a corrosion prevention method for the external part of underground natural gas pipeline. The SACP model were implemented in COMSOL Multiphysics utilizing the Secondary Current Distribution interfaces. In order to prevent these corrosions to occur on the pipeline surfaces, the Sacrificial Anode Cathodic Protection method (SACP) is applied using the COMSOL Multiphysics software. From the results it can be seen that the clay loam soil has a good electrolyte conductivity than sandy soil which has high resistivity. Therefore, SACP of underground natural gas pipelines can be best use in clay loam soil which has high electrolyte conductivity than sandy soil. This method is the simplest and low associated cost method to protect underground natural gas pipelines from corrosion.

Reference

- Karami, "Review of corrosion role in gas pipeline and some methods for preventing it," *Journal of Pressure Vessel Technology, Transactions of the ASME*, vol. 134, no. 5. 2012. doi: 10.1115/1.4006124.
- Mahasiripan, E. Viyanit, W. Pongsaksawad, B. Cherdhirunkorn, P. Sancharoen, and S. Tangtermsirikul, "Study of Aluminium and Magnesium Alloy as Sacrificial Anode for Corrosion Protection of Structural Steel in Artificial Seawater," no. September 2014, pp. 1–10, 2011, doi: 10.13140/2.1.3288.5128.
- Chalgham, K.-Y. Wu, and A. Mosleh, "External corrosion modeling for an underground natural gas pipeline using COMSOL Multiphysics," *Proc. COMSOL Conf. 2019*, 2019.
- "Dd 165,000," no. 800.
- R. Meagher, "Soil Impact Assessment and Rehabilitation study for the PNG LNG Project : Portion 152 LNG Facility For Coffey Natural Systems December 2008," no. December, 2008.
- S. Irmak, "Basic Soil and Water Resources and Irrigation Engineering / Agricultural Water Management and Related Terminology," *Inst. Agric. Nat. Resour.*, no. June, 2015.
- USDA, "Soil electrical conductivity: Soil health - Guides for educators. United States Department of Agriculture. Natural Resources Conservation Service," no. May, pp. 1–9, 2014.
- Dowsing, O. Wind, and N. Terry, "Internal Corrosion and Cathodic Protection," [https://www.usbr.gov/power/data/fist/fist4_5/FIST%204-5%20Final%20\(8-22-2013\)%20\(2\).pdf](https://www.usbr.gov/power/data/fist/fist4_5/FIST%204-5%20Final%20(8-22-2013)%20(2).pdf), vol. 4, no. April, pp. 43–44, 2013.
- Handbook, E. F. "CONTROL OF STEEL USED FOR K * f * Ps * Adj Re," no. March, 1979.
- Guyer, J. P. F. Asce, and F. Aei, "An Introduction to Cathodic Protection Principles," *J. Chem. Eng. Inf.*, vol. 877, no. 5, 2014.