Improve Sacrificial Anodes to Impressed Current in Puma Energy PNG Limited Throughout the Country

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Abstract

The cathodic protection of steel structures for Puma Energy in Papua New Guinea have been deteriorating since construction due to inadequate potential supply from the anodes. The magnitude of protection using sacrificial anodes have been considered inadequate and thus amount to failing CP systems throughout all parts of the country. This has been revealed via various other CP companies and commissioned by Puma Energy PNG Limited to carry possible inspection and maintenance on established structures. Because the sacrificial anodes entirely depend its potential difference between the cathodes and anodes, it is quite tedious and complex to adequately supply protective current throughout all intended structural path for effective protection. The sacrificial anodes cathodic protection system established throughout all Puma Energy terminals in the country have reported to have been failed. Massive and complex structures such as steel tanks of both underground and surface or pipelines have inadequately protected by the sacrificial anodes. As such, the company is looking for recommendations to improve sacrificial anodes to impressed current cathodic protection system. Port Moresby's Idubada CP terminal and Weak, East Sepik provinces have faced the same problems and is widely faced throughout the country. Puma Energy's facilities are deteriorating and failing CP protection and thus have been greatly recommended by various CP contactors to looking into possible replacement with impressed current method as it rendered effective protection than sacrificial anodes.

Keywords
Electrolyte, Impressed Current, Protected, Sacrificial Anodes, Unprotected

Introduction

Corrosion is inevitable in nature and cannot be stopped even by deploying sophisticated techniques. This is because iron ores when extracted from mines, it gradually went through many processes to become steel. However, when nature intense to converts into its original or stable states, it gradually forced through the process known as corrosion. The iron ores are in stable stage but when processed through various temperatures and convert to milled steel, it is known as unstable stage.

The corrosion occurs due to the presence of anode, cathode and an electrolyte. Without anyone one of this means no chemical reaction. Port Moresby and Wewak are located in the coastal where there's a lot of dissolved chloride content imminent. The chlorides are driven by wind from the coast and deposited into the structures where it eventually reacts with the steels and corrosion occurs. In these two centers, the type of protection is again sacrificial anodes and amount of cathodic protection is insufficient and very less (Mohamed 2015). Because the protective current from the sacrificial anodes systems entirely depends on its potential difference, the amount of current supplied is sometimes stray and impedance or weak. Such is true for all other centers throughout the country.

Sacrificial Anodes

Sacrificial anodes protective system is also applicable to onshore pipelines and tanks of both surfaced and underground. Most negative from electromotive series is commonly used due to its nature of inbuilt electromotive potential to drive the electrons from more active to less active.

The most active metals usually magnesium, zinc, and alloys of aluminum selected for the cathodic protection but without any external sources of voltages to drive the corrosive current through. Naturally existence electrochemical potential of electron ions continue to discharge and polarize the anode while cathode in turn receives the protective electrons. In the process, the anode reacts with the oxygen and dissolve chloride and form oxides and becomes iron oxides (rust) and ultimately corrodes away (Mohamed et al. 2012).

In sacrificial anodes, the electrical circuits are connected from anode to the structure (cathode) and so doing the anode will corrode and consequently discharge an electric current to the pipeline in which the theory discussed is accomplished (Lilly et al. 2007). The electrons of both corrosive and protective travels through connection cables and discharge via electrolyte as shown in figure 1. Because the electrons are not facilitated by any external sources, the potentials of sacrificial anodes may be diminished or reduce in voltage and thus electrolytic resistivity underground can force the protective electrons away and consequently structure may be corroded.

Unlike impressed current cathodic protection, the potential supply to force the electrons from anode to cathode is achieved from naturally inherent electrical forces.

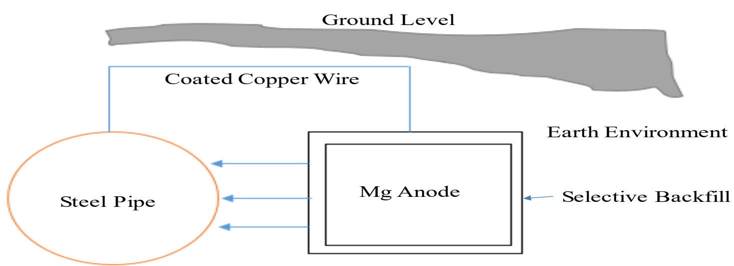

Figure 1. The prototype of sacrificial anode system installation to protect oil and gas pipelines.

The anodes packed and covered in a backfilled consisting of electrical current passable such as 75% gypsum, 20% bentonite, and 5% sodium sulfate and workable granular soils. This is because more resistance the electrolyte, the cathodic protection wont eventuate and thus results in corrosion of the structure. The main purpose of the backfill with selective materials is to keep the water from the selective materials which will emit the protective electrons from anode to the structure and thus keep the pipelines protected as designated on figure 1.

The sacrificial anode does not need external power source but utilizes the naturally existing potential within to drive the protective electrons from anode to cathodes. Advantages of the sacrificial anodes is that they supply their own power from within, requires minimal maintenance, thus cost savings. However, sacrificial anodes system is only applicable, necessary and recommended for well coated structures thus minimized chances of being corroded during its service life. Puma Energy centers in Port Moresby and Wewak uses sacrificial anode method to protect its steel facilities.

Importance of Sacrificial anodes

The sacrificial anode method is preferred over impressed current cathodic protection system due to its simplicity in installation and maintenance free operation for the duration of its service life. Unlike impressed current method, it is quite cheap and requires less effort during installation and nil visit to site for maintenance.

The different types of anodes used includes aluminum, zinc and magnesium depending on their availability, cost and importantly naturally existing potential to drive the protective current for effective protection (LTD 2015). Because it uses naturally occurring potential in anode to drive protective current through electrolyte, the tendency of corrosion is imminent compared to impressed current. The sacrificial anodes or galvanic protection system is considered reliable and cost effective as it does not incur much from the start to end during instillation.

Ferrous metals used in structure such as pipelines (both onshore and offshore), tanks and other structures require more of electrochemical potential of magnesium in sacrificial anodes. Prior to implementation of impressed current system, sacrificial anodes were mostly used to protect important economic structures such as those mentioned above for protection from corrosion (Loto et al. 2019).

Because tendency to loos electrons by magnesium is even greater than other elements, it's becoming more anodic and hence, instead of the cathode electrode loses its electrons, magnesium sacrifices its electrons to protect and keep the steel structures in-tacked. By considering the less anodic in electromotive force series, magnesium can become overall sacrificial anodes for iron, zinc and aluminum (Quale et al., 2017). As designated on figure 10, the equations for cathode and anode are as follows; Magnesium (sacrificial anodes, oxidation) $Mg \rightarrow Mg^{2+} + 2e^{-}$ and protected steel structure (Cathode pipe) $Fe^{2+} + 2e^{-} \rightarrow Fe\ (s)$

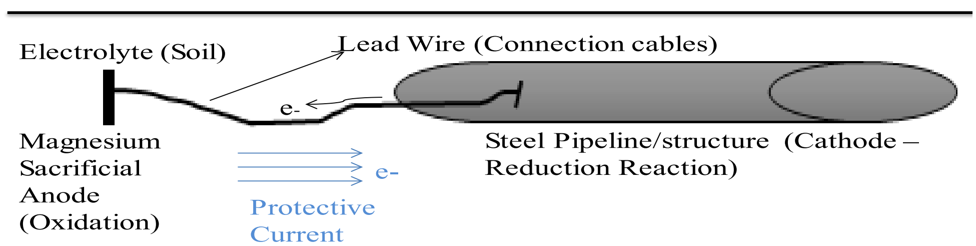

Figure 2. Magnesium (Mg) anode sacrificed to protect the steel pipeline from corrosion (Byrne et al. 2016).

Electrolytic Resistivity

High the electrolytic resistivity would mean that less protective current is supplied to the cathode and more corrosion is possible. It is important for thorough investigation into the electrolyte prior to sacrificial protection is installed to ensure effective protective electrons are supplied through soil, water or any medium (Torstensen 2012). This further means that the resistivity of soil is inversely proportional to the flow of current. When there is high resistant in electrolyte, the flow of current is minimized and subsequently, degree of cathodic protection is minimized.

Unlike impressed current, sacrificial anodes used only excited potential within the anodes and not external power source to force the current through. As such, it is paramount that electrolyte in which the exchange of ions taking place during polarization has to be selective and determined prior to complete instillation. It is also necessary that selective earth is required to fill or cover the anode to avoid intense resistance.

During polarization, most negatively charged anode lose electrons to cathode and oxidized to form ion oxides. The lost electrons are then gained by cathode and in the process, the cathode is prevented from corrosion where anodes are sacrifice instead of cathode. As known from early discussions, electrons are lost from more negatively charged elements where oxidation is possible on anodes while lost elections are gained at cathode. This theoretical reaction is the fundamental principal in which the cathodic protection system is derived and is practically used throughout for the purpose of protecting structures and be able to survive and provide service for its design life without failure.

One of the prerequisite in installing sacrificial anodes to effectively understand electrolyte (soil/water) resistivity so the amount of protective electrons transmitted by anodes is not clogged neither prevented from passing through and thus, its only proper to carefully analyze environmental conditions where electrolyte is selected or back filled to allow for perfect electrons transfer. Greater the soil resistance would demand more anodes in quantity to reinforce its potential (driving forces) to be able to reach cathode/structure for protection. It further implies that quantity of anodes installed is determined by electrolyte to supply adequate electromotive charges to the cathode. As the soil resistance increases, protective current transmission is flawed and disturbed and consequently decreases as confirmed according to Ohm's law. When less or single anodes are installed in a highly resistive electrolyte, the current flow is disturbed and clogged because it does not have sufficient potential (driving force) to drive through resistive electrolyte. High resistance will drag electromotive charges and some lost along its way due to friction. Eventually the cathode electrode will corrode as less protective electrons and few entering cathodes will react with dissolved oxygen or chloride ions thus nil protection is imminent on the cathode electrode.

Studies from different sources have derived few facts as designated per the table 1. The data have been obtained from an experiment done in Iraq soil.

Table 1. List of data on possible conductivity and resistivity of various soils.

Concentration (NaCl%)	NaCl content (g/l)	Conductivity μΩ/cm	Resistivity (Ω.cm)
0.01	0.100	00200	005,000
0.05	0.500	001,000	001,000
0.10	1.000	001,666.66	00600
001	10.00	0020,000	0050
003	30.00	0040,000	0025

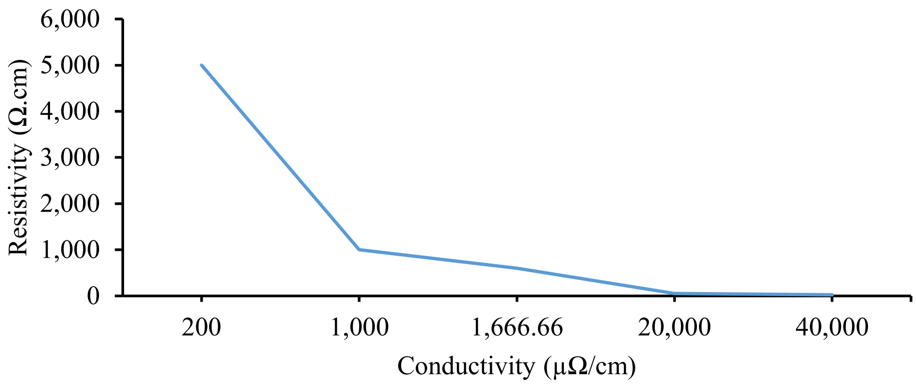

Figure 3. Graph showing as resistivity increase, conductivity decreases

Table 1 contains the resistivity (Ω.cm) from moderate to server conditions in Iraq. It can be noted from figure 3 that as concentrated ions of sodium chloride (NaCl) increases, the resistivity reduces. This means the electrolyte conductor (soil) is inversely proportional to resistance but directly proportional to sodium chloride concentration. If there is more electrolytic resistivity present, the flow of current is minimized and thus potential of anode needs to be increased and which needs more anodes reinforcements for efficient flow of electrons.

Impressed Current Cathodic Protection System

The impressed current corrosion prevention system requires external power supply source to mitigate and minimize corrosion on steel structures. The process requires adequate visit on regular bases to ensure the system is functional for its design life.

As power supply source known as rectifier continues to supply driving current which drives the potential from anode to cathode, it deposits protective electrons onto the cathode and as a result, the anodes corrode thereby protecting the cathode. Principal in which impressed current operates is same as that of sacrificial anode, however it has external power supply source attached to the system which effectively prevents the structure from corrosion.

The transformer rectifier controls the current when polarized from anode to cathode. As the current is turned on, the protective electrons are driven from anode thus deposited into the cathode and in the process, the corrosive electrons on cathode is then forced through the electrolyte from cathode to anode. The structure (cathode) is protected from corrosion when anode undergoes corrosion. This is illustrated in figure 4 where the same principal is applied throughout all electrolyte (soil, water etc.).

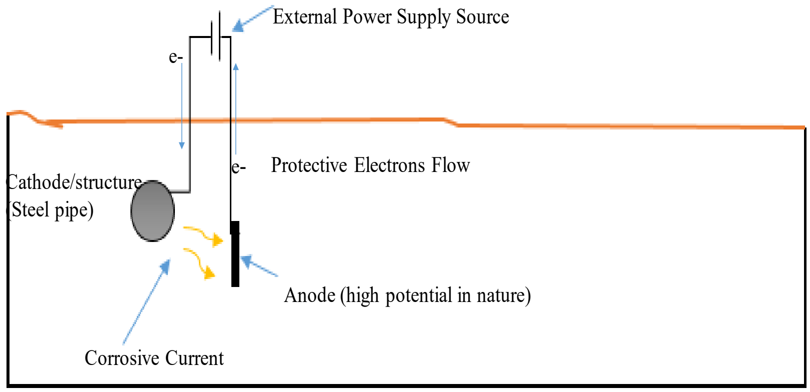

Figure 4. Shows the impressed current in onshore buried pipelines.

Test Results from Idubada SACP Terminal (PNG)

Anodes installed at Idubada (Port Moresby) have considered to function but gradually weak and vulnerable to have reduction in strength to adequately supply potential to drive the impressive current through electrolyte.

Table 2. Copper Sulfate and silver chloride electrode used in Idubada Puma Energy PNG based.

Location	Reference Electrode	Protected (V)	Unprotected (V)		
Idubada (PNG) Different Locations as discussed in Materials and Methods sections	$Cu/CuSO_4$	-1048	-1058		
	$Cu/CuSO_4$	-1201	-1211		
	$Cu/CuSO_4$	-1155	-0422		
	$Cu/CuSO_4$	-1169	-0480		
	$Cu/CuSO_4$	-1231	-1255		
	$Cu/CuSO_4$	-1256	-1157		
	Ag/AgCl	-0900	N/A		
	Ag/AgCl	-0895	N/A		
	Ag/AgCl	-0896	N/A		
	Ag/AgCl	-0883	N/A		
	Ag/AgCl	-0895	N/A		
	Ag/AgCl	-0896	N/A		

Protected Structure (Blue Line)

Protected structure indicated by blue line performs exceptionally (figure 5) well by supplying electromotive force to drive the current, there is still existence of stray current due to calcareous materials within the electrolyte. The corrosion engineer needs further investigation on this as more values seemed to fall in between -900 to -1200 millivolts which is an indication of impressed current system. All systems shown have been protected by sacrificial anodes and thus, requires thorough investigation on this. The possible reason could be due to flow of current only on certain track and in metal substrate leaving other portion of the surface to corrode and fail.

Unprotected structure (Orange Line)

The unprotect sections have fallen way below and towards zero. According to Australian standards and specification guidelines AS2832.1.2015, there is no possible cathode protection. The structure is extremely in danger of collapse and leakage. It really needs cathodic protection where Idubada is no excuse.

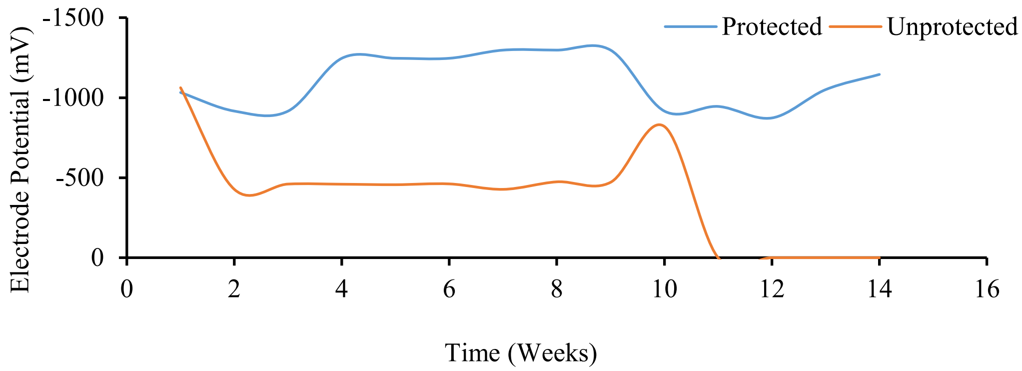

Figure 5. Showing the CP results of Idubada Puma Energy terminal.

As noted from Idubada sacrificial anodes system, current density is quite tedious due to the distance between anode and cathode. The reason being that when power or current density is reduced by the distant location of cathode from anode, the electrolyte resistance profoundly affects the flow of current from anodes. As such, there is not enough power transfer to polarize the structure.

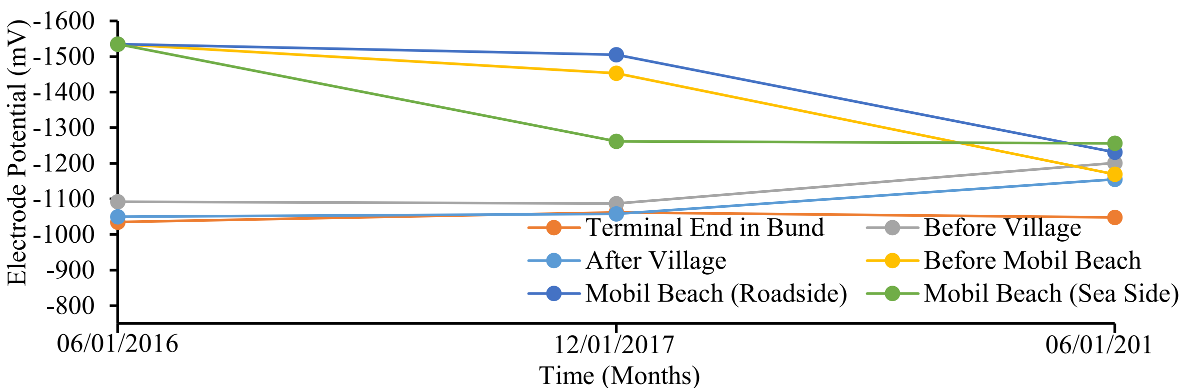

Figure 6. Puma Energy Site Terminal

From figure 6, almost all CP results do not fall between -850 mV to -900 mV. This clearly indicate the structure to have been exposed to corrosion and are in terribly in bad conditions. The Puma Energy CP engineers need to considered for possible rectification for immediate maintenance and also consider for replacement options as sacrificial anodes do not provide adequate protection level in accordance with international standards of CP system.
Current density has been consumed by electrolyte and as a result, there is an obvious jump in unprotected (orange line) from -820 to 0 millivolts. It is a clear indication that the electromotive potential from anodes were inadequate and cannot reinforce the flowing current from anode to cathode. As such, there was drastic reduction in protective current when travelling through which the current have seen hindered by the electrolyte (soil).

Wewak Sacrificial Anodes CP (PNG)

The table 3 displayed the raw data collected from Wewak Puma Energy terminal of Papua New Guinea. The test was conducted from the month of January 2019 and accomplished in the month of December 2020. The data were sent via email by Puma Energy for possible interpretation and appropriate recommendation of the methods to combat, control and mitigate deteriorating state by corrosion and recommend possible remedies and further protection mechanism for Puma Energy facilities in PNG.

Table 3. The Results of Wewak CP Terminal (PNG)

Wewak CP Results.						
Location	Insulating Flanges	Unprotected (mV)	Protected (mV)	Pass/Fail	Max Protced (mV)	Reference Electrode
Pump Pad	ULP	-508	-1155	Pass	-850	$Cu/CuSO_4$
	ADO	-507	-1246	Pass	-850	$Cu/CuSO_4$
	Kerosine	-507	-1111	Pass	-850	$Cu/CuSO_4$
Gantry	ULP	-330	-0984	Pass	-850	$Cu/CuSO_4$
	ADO	-332	-1071	Pass	-850	$Cu/CuSO_4$
	Kerosine	-331	-0936	Pass	-850	$Cu/CuSO_4$
Drum Dock	ULP	-386	-1034	Pass	-850	$Cu/CuSO_4$
	ADO	-382	-1122	Pass	-850	$Cu/CuSO_4$
	Kerosine	-382	-0986	Pass	-850	$Cu/CuSO_4$
Test Point 1	150mmPL	-460	-1213	Pass	-850	$Cu/CuSO_4$
Test Point 2	150mmPL	-782	-1166	Pass	-850	$Cu/CuSO_4$
Test Point 3	150mmPL	-810	-1130	Pass	-850	$Cu/CuSO_4$
Test Point 4	150mmPL	-450	-0990	Pass	-850	$Cu/CuSO_4$

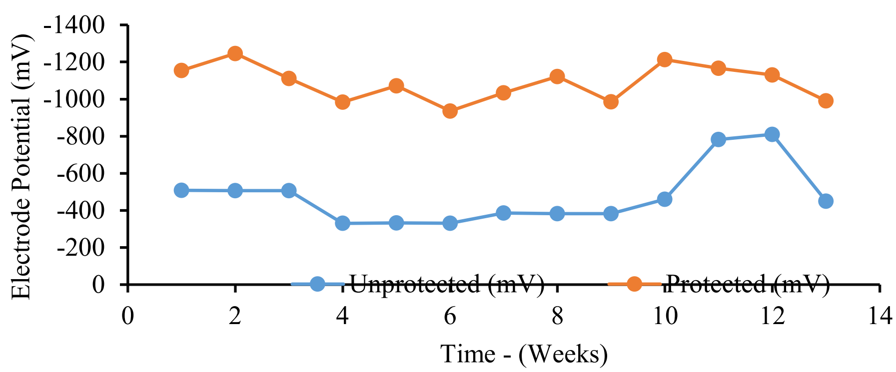

Figure 7. The graph showing the data obtained from sacrificial anodes CP system in Wewak.

As per the Australian and New Zealand standards CP manual AS2832.1.2015, the protected portion (figure 7) values steady at -850 millivolts (mV) and is considered pass for sacrificial anodes. However, the data collected above were in random order and fluctuates but do not fall below -0.85 V. The protected sections of the facilities were considered pass but this does not mean all were safely and effectively protected. According to the CP manual, the facilities considered to have stray current and formation of calcareous materials. This is why the values for protected sections were considered pass.

The unprotected sections of the facilities in Puma Energy based PNG limited were also failing and data do not give sufficient guarantee of optimum stability. The corrosion engineer needs to check the structures and if possible call for rectification as soon as possible. This is because values of unprotected structure fall way below -0.5 which the corrosion engineers consider to have no CP protection or failing CP. The structure is in danger according to table 6 of the Australian standard manual AS 2832.1.2015.

Conclusion

As noted from data and graphs, it can be concluded that the amount of CP protection rendered to the facilities were considered to be insufficient and weak. This is due to stray current but most probably because of the weak nature of the potential supplied by the anodes which profoundly resist the flow of impressive current.

As such, it is highly recommended that Puma Energy PNG limited needs to install impressed current cathodic protection system because it effectively protects the structures from corrosion. The amount of protective current rendered by impressed current is more sufficient and adequate to protective even a larger structures compared to sacrificial anodes. The main advantage of impressed current method is the external power supply source that reinforces its natural potentials from the installed anodes. Thus Port Moresby and Wewak needs to improve its sacrificial anodes systems to impressed current methods including other centers around the country.

Notes:

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Author contributions

NM analyzed and interpreted all the data related to this study and writing the manuscript and AM performed a major contribution in recommending for editing and guiding NM for better manuscript. All the authors read and approved the final manuscript.

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Compliance with ethical standards

Conflict of interest

The authors declare of having no conflict of interest.

Ethical approval

This study requires no ethical approvals.

Informed consent

Informed consent after explaining the nature of investigation was obtained from each participant in this study.

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