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Investigation on the Potentials of Locally Produced Anodes for Impressed Current Cathodic Protection of Pipelines in Aggressive Environment

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Abstract- Impressed Current Cathodic Protection (ICCP) system has been adjudged to be the most acceptable corrosion mitigation procedure today. Integrity of ICCP systems depends among other important factors on the Anode material. Platinize-Titanium base materials were found to be the best anodes in ICCP systems but with high importation cost. In order to improve local contents and foreign exchange, an investigation was carried out on the potentials of locally produced anodes for ICCP system. Four Anodes were produced from different materials for this purpose. An aggressive environment was simulated by saturating soil with 1M solution of NaCl to form corrosion cells. A set of steel Pipe and Anode were buried in four different corrosion cells powered with direct current source to represent an ICCP system where the Anode performances were monitored in terms of depletion period, level of corrosion protection offered to the steel pipes and general electrochemical behavior of both the Pipes and the Anodes. Readings of the simulated corrosion cells environments' pH, pipe-to-soil potentials based on Cu/CuSO₄ reference electrode, open circuit voltages and temperature were taken on daily basis. The test lasted for twenty-one days with the Anode from Lead material exhibited a good protection quality by showing only 10.22% depletion in comparison to the Cupper based and Aluminum based Anodes. From the results, it was concluded that Pb-based Anode produced locally can be a good candidate for ICCP system in aggressive environments.

Indexed Terms- Anode Materials, Corrosion Mitigation, Impressed Current Cathodic Protection, Cu/CuSO₄ reference electrode, Locally Produced Anode, Pipe-to-Soil Potential, and Simulated Aggressive Environment.

I. INTRODUCTION

Metals always have tendencies of returning to their original ore form of oxide when expose to favorable condition due to instability and high energy level as a result of enormous heat expended during the process of refinement from their ores. This process is known as corrosion [1]. Generally, Corrosion can be described as a physiochemical interaction between a metal and its environment, which may result in changes in the properties of the metal that may lead to impairment of the function of the metal, the environment, or in the technical system of which these form a part [2].

Lots of resources are invested in the processes of producing metals from their naturally occurring ores, therefore, care must be taken to ensure that metals are not allowed to revert back to their original form as this will result in enormous lost in terms lives, capital, materials, and labor. In order to avoid this, industrialized nations like the United States of America used to spend over \$270 billion – approximately 3.1% of the nation's Gross Domestic Product (GDP) to control corrosion annually from which over \$7billion is for corrosion control of pipelines for transportation of Gas and liquids [3] and [4].

It is therefore important that industrial nations focus more attention to corrosion control as lack of it could cause great lost to economy in terms of lives and properties and serious environmental degradation as a result of possible spillage if the metallic structures are in the oil and gas region [5] and [6]. Unlike weather-related disasters, there are several methods of preventing and controlling corrosion by reducing or eliminating its impact on public safety, the economy, and the environments [7]. Among these methods, Cathodic Protection (CP) has shown to be the only one that could provide complete or acceptable level of protection against corrosion in environments that have conductive electrolyte [8], [9], [10], and [11]. In their work, [2] reported that many researches in the last decades indicated that CP systems are the most promising method of mitigating corrosion of pipelines. There are two types of CP systems – Sacrificial Anode and Impressed Current Cathodic Protection (ICCP) type. The latter is mostly applied in Oil and Gas Industries due to the former's inability of producing adequate current density especially for large structures and poorly coated ones [12]. However, there some major challenges which includes proper function of anodes with respect to materials during the design and functions of ICCP systems.

From the pool of tested ICCP anodes, Platinized-Titanium anodes based material has proved to be more efficient and required protection but relatively too expensive [13], hence, the need to search for a less expensive combination of materials which can be source locally in order to develop local technology that could conserve nation's scarce foreign exchange. In this paper, a study was conducted to assess the performance of locally produced anodes based on their corrosion resistance and electrical conductivity qualities with a view to ascertain a possible combination that will serve best as good anode for ICCP systems in aggressive environment.

II. METHODOLOGY

Alloys of selected metals were produced based on their electrical and corrosion behavior in casting the anodes used in ICCP system for the purpose of assessing their potentials in adequately protecting steel pipes buried in aggressive environments. The following combinations of the alloys were reached base on solid solubility of one in the other, corrosion behavior and electrical conductivity:

a) Aluminum 90.6%/Copper 9.4%
b) Copper 90%/Aluminium 10%
c) Copper 95%/Aluminium 5%
d) Lead 100%

The casted and machined Anodes are shown in Fig. 1.

A. Experiment

To assess the performances of the anodes, corrosion cells were produced to simulate aggressive environments such as the riverine areas where most oil and gas structures were either buried or submerged. Soils were saturated with solutions of NaCl salt in wooden boxes with steel pipes and anodes buried after connecting positive terminals of direct current (dc) to the anodes and negative terminals to the anode according to NACE standard on ICCP specifications as shown in Fig. 2. In each of the four corrosion cells a polished steel pipe and anode were buried. The pipes were well polished to remove any traces of corrosion products for proper assessment of the protection potentials of the ICCP system using the produced anodes that has machined grooved neck meant for proper and firm attachment of electrical connections and for taking reading of pipe to soil potentials using $Cu/CuS0_4$ reference electrode. The corrosion cells were powered with dc current throughout the period of assessment.

Measurements of the open circuit voltages, temperatures of the cells, pH of the cell environment and pipe-to-soil potential using appropriate measuring instruments were taken throughout the period of the experiment. Visual examination of the anodes was carried out at intervals of twenty-four hours with particular emphasis on dissolution pattern.

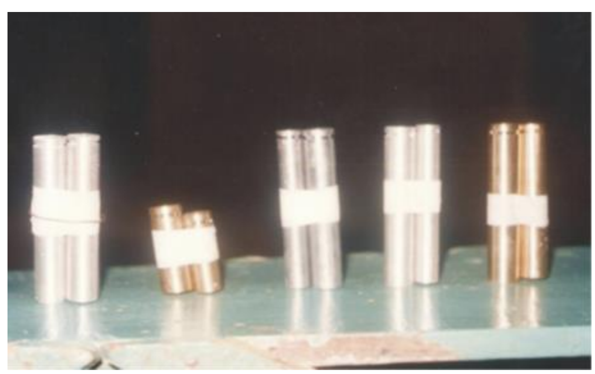

Fig. 1: Casted and Machined Anodes Produced Locally

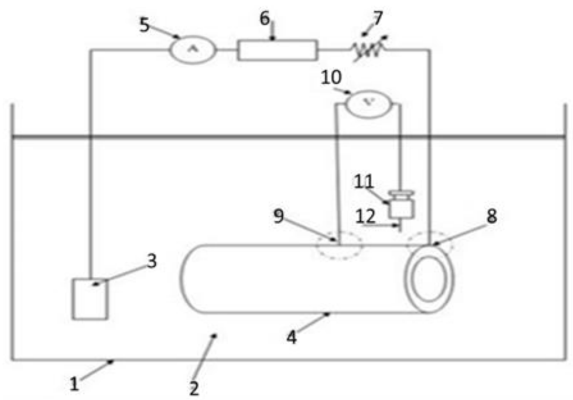

Fig. 2: Schematic diagram of corrosion cell

Legend

1 Wooden box	2 Electrolyte
3 Anode	4 Pipe
5 Ammeter	6 Solar power
7 Resistance box	8 Drain point
9 Test point	10 Voltmeter
11 Reference electrode	12 Capillary tube

III. RESULTS AND DISCUSSION

Measurements of anode dissolutions with time, changes in environmental pH, pipe-to-soil potentials, and temperatures were taken throughout the period of experiment for the four corrosion cells where conclusions were made with respect to the performance of the locally produced anodes for cathodically protecting steel pipes in aggressive environment.

A. Anode Depletion Rate

The rate at which the anode was depleting as they offer protection to the buried pipes was recorded as shown in Table I.

From Table I, it can be seen that Aluminum based anode (Al 90.6%, Cu 9.4%), depleted in four days from the start of the experiment, recording 86.82% depletion, which disqualified it as anode for ICCP systems in aggressive environments. Copper based anode (Cu 90%, Al 10%), depleted in eight days, recording 88.21% depletion, an indication that it cannot be used as anode aggressive environments. The second Copper base anode (Cu 95%, Al 5%), showed a percentage depletion of 25.93% after twenty-one days, this too is not a candidate for ICCP system anode in aggressive environment. The Lead anode showed a percentage depletion of only 10.22% after twenty-one days. This is an indication that Lead anode could be used for aggressive environment. Figs. 3, 4, 5 and 6 showed the anodes conditions before and after the tests. The criteria for the performance test were long lasting (life), corrosion resistance and rendering effective cathodic protection to the buried pipes as determined by $Cu/CuS0_4$ reference electrode and visual examinations.

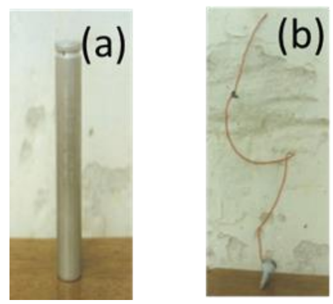

Fig. 3: Al 90.6%, Cu 9.4% Anode (a) before the experiment and (b) after the experiment

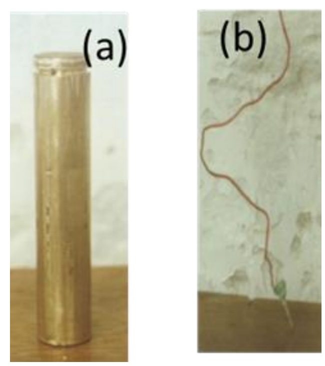

Fig. 4: Cu 90%, Al 10% Anode (a) before the experiment and (b) after the experiment

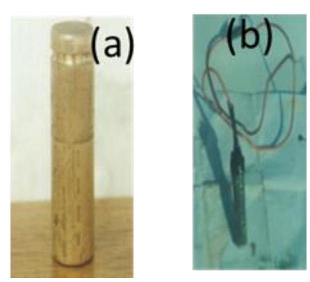

Fig. 5: Cu 95%, Al 5% Anode (a) before the experiment and (b) after the experiment

Table I: 24 Hourly Size of Anode and Percentage Depletion

Time (hours)	Cu 95% Anode		Al Anode		Pb Anode		Cu 90% Anode	
	Size	%dp	Size	%dp	Size	%dp	Size	%dp
0.00	2.025	0.00	2.20	0.00	2.25	0.00	2.12	0.00
24.00	2.000	1.23	1.65	25.00	2.25	0.00	1.825	13.92
48.00	1.965	2.96	1.10	50.00	2.25	0.00	1.56	26.42
72.00	1.955	3.46	0.355	83.86	2.25	0.00	1.46	31.13
96.00	1.865	7.90	0.29	86.82	2.25	0.00	1.00	52.83
120.00	1.800	11.11	-	-	2.23	0.89	0.74	65.09
144.00	1.790	11.60	-	-	2.23	0.89	0.675	68.16
168.00	1.780	12.09	-	-	2.22	1.33	0.445	79.01
192.00	1.740	14.07	-	-	2.22	1.33	0.25	88.21
216.00	1.740	14.07	-	-	2.135	5.11	-	-
240.00	1.740	14.07	-	-	2.135	5.11	-	-
264.00	1.705	15.80	-	-	2.135	5.11	-	-
288.00	1.705	15.08	-	-	2.135	5.11	-	-
312.00	1.705	15.08	-	-	2.135	5.11	-	-
336.00	1.700	16.05	-	-	2.080	7.56	-	-
360.00	1.700	16.05	-	-	2.080	7.56	-	-
384.00	1.685	16.79	-	-	2.025	10.00	-	-
408.00	1.555	23.21	-	-	2.025	10.00	-	-
432.00	1.555	23.21	-	-	2.02	10.22	-	-
456.00	1.555	23.21	-	-	2.02	10.22	-	-
480.00	1.525	24.69	-	-	2.02	10.22	-	-
504.00	1.500	25.93	-	-	2.02	10.22	-	-

Key: %dp = percentage depletion

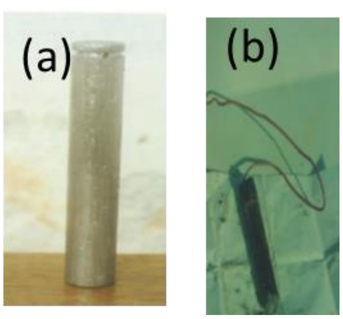

Fig. 6: Cu 90%, Al 10% Anode (a) before the experiment and (b) after the experiment

B. pH changes in test environments

The pH in the four cells did not exceed 6.97 which was an indication that the environment remained aggressive throughout the period of test even though the readings of the pipe-to-soil potential indicated appreciable level of protection.

C. Pipe potential

The pipe-to-soil potentials using $Cu/CuSO_4$ reference electrode for the various corrosion cells range from -0.852V to -1.915V which indicated a good protection level signifying that the pipes were receiving protection.

CONCLUSION

An understanding of the anode performance in aggressive environment provided a clue for the selection of appropriate local alloy material for cathodic protection of buried or immersed steel structures.

All the anodes used protected the structures they were meant to protect. However, the aluminum base anode (Al 90.6%, Cu 9.4%) and 90% copper base anode exhibited poor depletion rate.

The 95% copper base anode exhibited a good corrosion resistance while the lead anode exhibited a better corrosion resistance to the aggressive environment, this outstanding performance singled out lead anode as the appropriate local, cheap, available and long-lasting anode material for impressed current cathodic protection of buried or submerged structures in aggressive environment.

REFERENCES

[1] Centre for Window & Cladding Technology. Technical Note No. 24, CORROSION. Retrieved July 16, 2015, from: www.cwct.co.uk

[2] P. C. Onyechi, N. S. P. Obuka, C. O. Agbo and C. A. Igwegbe. (January-February 2014). Monitoring and valuation of cathodic protection performance for Oil and Gas pipelines: A Nigeria situation. *International Journal of Advanced Scientific and Technical Research* [online]. *4*(1). pp 47-65. Available: http://www.rspublication.com/ijst/index.html

[3] Cathodic Marine Engineering, (2014). Cost of Corrosion in United States of America. Retrieved July 16, 2015, from: http://www.cathodicme.com

[4] A. Zaki. (2006). Principles of Corrosion Engineering and Corrosion Control, 1st Edition, Butterworth-Heinemann, ISBN 9780750659246, Elsevier Ltd.

[5] E. J. Akpabio, E. J. Ekott and M. E. Akpan. (2011). Inhibition and control of microbilogically influenced corrosion in Oilfield materials. *Environmental Research Journal* [online]. 5(2). pp 59-65. Available: http://medwelljournals.com/abstract/?doi=erj.2011.59.65

[6] B. O. Oluwatobi and M. A. Gbenga. (2013). Laboratory studies on the influence of crude oil spillage on lateritic soil shear strength: A case study of Niger delta area of Nigeria. *Journal of Earth Sciences and Geotechnical Engineering* [online]. 3(2). pp 73-83. Available: https://www.semanticscholar.org/paper/Laboratory-Studies-on-the-Influence-of-Crude-Oil-on-Ltd-Oyegbile/681c469ca2af65affa49196f91b9ff7911862386

[7] Günter Schmitt (2009). Global Needs for Knowledge Dissemination, Research, and Development in Materials Deterioration and Corrosion Control. The World Corrosion, NACE International 1440 South Creek Drive, Houston, TX, USA 77084-4906

[8] M. H. Parsa, S. R. Allahkaram and A. Ghobadi. (June 2010). Simulation of cathodic protection potential distributions on oil well casings. *Journal of Petroleum Science and Engineering,* Elsevier [online]. 72(3-4). pp 215-219. Available: https://www.sciencedirect.com/science/article/abs/pii/S0920410510000768

[9] A. Mathiazhagan. (October 2010). Design and Programming of Cathodic Protection for Ships. *International Journal of Chemical Engineering and Applications* [online]. 1(3). pp 217-221. Available: http://ijcea.org/papers/36-A530.pdf

[10] A. A. Naseer and F. A. Shahad. (March 2013). Simulation of Cathodic Protection System Using Matlab. *Iraqi Journal of Chemical and Petroleum Engineering* [online]. 14(1). pp 25- 37. Available: https://www.iasj.net/iasj?func=fulltext&aId=69119

[11] M. Z. Al-Faiz and L. S. Mezher. (January 2012). Cathodic protection remote monitoring based on and wireless sensor network. *Wireless Sensor Network*. 4(9). pp 226-233. Available: https://www.scirp.org/journal/paperinformation.aspx?paperid=22513

[12] B. B. John. (2012). Impressed Current Cathodic Protection System Design. Corrosion and Cathodic Protection Theory. Bushman and Associates, Inc., Medina, Ohio. Available: https://www.academia.edu/5246527/Corrosion_and_Cathodic_Protection_Theory

[13] M. G. Fontana. (1987). Corrosion Engineering. (3rd ed.) New York, McGraw-Hill International Edition. ISBN-13: 978-0070214637 ISBN-10: 0070214638

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