PIPELINE CORROSION CONTROL USING PHOTOVOLTAIC MODULES: THE ENVIRONMENTAL IMPLICATIONS

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Abstract

Pipelines provide the most efficient and safe means of transporting liquids and gases over long distances and any spillage due to corrosion can be very gradual and unnoticeable with resulting environmental effects. This study seeks to obtain the level of inhibition of pipelines corrosion using photovoltaic modules. Two ungalvanized pipes were buried in the Nsukka environment of average pH value 5.0. One of the pipes was protected while the other pipe was not protected. The gravimetry technique was used to analyze the pipes after a period of three months. The result indicated 75.0% level of protection and thus a prolonged life-span for the protected pipeline

Keywords: *photovoltaic modules, corrosion control, and environmental implications.*

1. Introduction

Oil spills occur on land and in water despite prevention efforts. They vary in scale, from just a few hundred litres to millions of litres. Preparing a timely and coordinated response to such an emergency of undefined magnitude that can happen at any time is an enormous challenge that requires significant planning and training. Environmental and economic effects of oil spill can be avoided by preventing them in the first place, Way et al (1999). Oil spills on land; rivers, bays and the ocean are mostly caused by accidents involving tankers, barges, pipelines, refineries and storage facilities. They are often harmful to marine birds, mammals and, sometimes, fish and shellfish, American Petroleum Institute (1999). It is also responsible for extensive environmental deterioration, including damage to agriculture and wildlife, erosion and soiling of buildings, and degradation of visibility when flared, Gordon (1991).

The majority of service interruptions in large metallic infrastructures and oil or water pipelines can be attributed to corrosion. Costs associated with system infrastructure failures are very high. Therefore the goal is to prevent failures from occurring, thereby extending the service life of the capital plant. This approach is preferred to a program of failure management, where service interruption, product spillage, losses to personal property, disasters, personal injury and even death are all possibilities. Although there are other infrastructure failure mechanisms, corrosion is a major factor in the deterioration and failure of oil industry metallic infrastructure. This cost of corrosion can be attributed to loss of useful life of equipment, cost of corrosion mitigation, litigation and downtime. By understanding the current infrastructure condition, defining the corrosion mechanisms, delineating corrosion rates and understanding the environment corrosivity, projected life-span calculations can then be made. These studies are then utilized to develop infrastructure life extension options for economic analysis. Replacement of iron and steel products (such as pipes) due to corrosion caused by inadequate or zero protection amounts annually to about 2% of the total tonnage of such products in use, Uhlig (1965). It has been argued that about 27% of the bursting of pipes could be attributed to corrosion, which could probably have been avoided, Parker (1962). In Alaska, U.S.A., the citizens are still experiencing the negative effects of the *Exxon Valdez* oil spillage that occurred on March 24, 1989. More than 25 fish species were destroyed by the accident, which also severely affected the livelihood of the residents who depend on the fish, and animals, Shell Nigeria (1999).

Annual rate of oil spills due to corrosive pipelines continue to increase in Niger Delta region of Nigeria due to inadequate protection of oil pipelines. According to its data, one of the oil companies operating in Niger-Delta admitted that there were 815 oil spills between 1997 and 1999, out of which 170, an alarming 20.85%, were caused by corrosive pipelines, Shell Nigeria (1999).

Corrosion activity affects piping systems to varying degrees generally dependent upon the piping service, quality of the steel, age, its size and layout, joining method, chemical treatment protection, engineering design, and the specific corrosion mechanism involved. Under the most severe conditions, it may be impossible to save the piping system from premature failure. In such cases, effort usually focuses on minimizing damage and operating problems, replacing pipe as necessary, and extending its service life as best possible. Preventing such corrosion problems from developing is clearly desired. Corrosion coupons still exist as the most widely used form of corrosion measurement and monitoring today, Duncan (2000).

In Nigeria, most pipeline networks are in remote locations where grid electricity supply is not available. Where grid electricity is available, the National Electric Power Authority (NEPA) does not supply it regularly either. In this study, we have used PV modules to generate direct current for the protection of pipelines against corrosion. The expected life spans of the pipelines were also calculated. The corrosion monitoring technique used is the gravimetry (corrosion coupon) technique, Aniekwu (2000).

2. Method

Several techniques for corrosion control and protection have been developed as means of reducing the effects of the environment on metallic materials, Burns and Bradley (1967). Cathodic protection of pipelines against corrosion is widely employed either by galvanic or electrolytic methods. With the galvanic method, the sacrificial anodes used to protect buried pipelines have to be replaced from time to time. With electrolytic cathodic protection, the corroding object is made the cathode of an electrolytic cell, which is supplied with direct current from an outer current source (e.g. rectifier). The auxiliary anode of this cell is usually insoluble (Pt, Pb, C, Ni), but may sometimes be soluble (Fe, Al), Weaver (2000). In order to achieve cathodic protection, Twort (2000), the pipeline to be protected is (purposely designed to be) the cathode of an electrochemical cell, which protects it from environmental attacks (corrosion) by immunity.

In carrying out this study, two ungalvanized steel pipes (designated as A and B) were bought from the Nsukka local market and laid in the sub-soils of known pH and resistivity. Pipe A was cathodically protected while pipe B was not protected. Two photovoltaic (PV) modules were used to supply the required impressed direct current needed for the protection of pipe A. The negative terminal of the current source was connected to the cathode (the pipe to be protected) and the positive terminal to the anode thereby completing the required electrical circuit needed for cathodic protection of the pipe. A reference electrode of $Cu/CuSO_4$ and a digital multi-meter were used to take readings of pipe-soil potential along the pipelines, Fig.1.

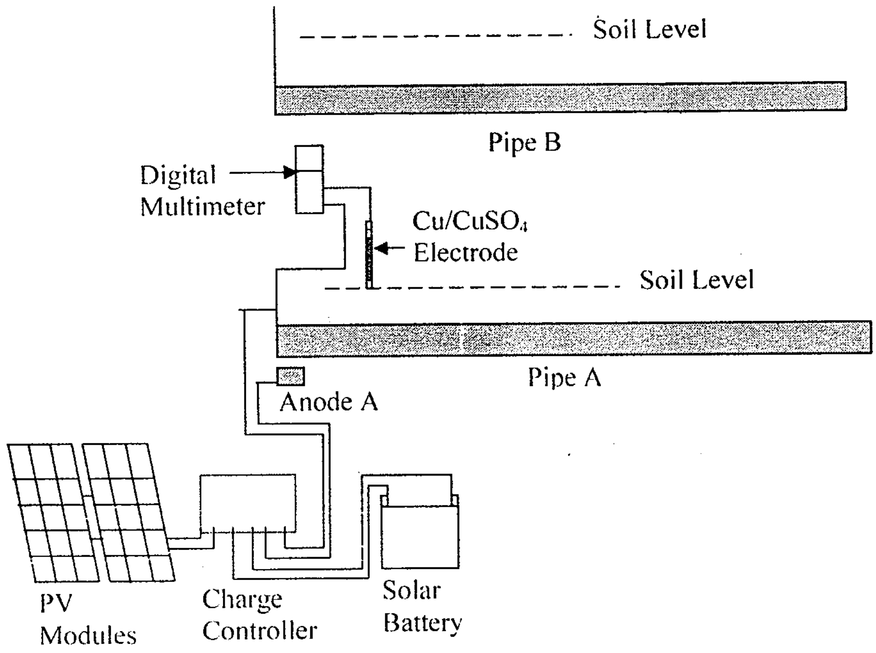

Fig.1: Cathodic protection of pipe A using photovoltaic modules

Nsukka is geographically located in the tropics with much solar irradiance, so the insolation was enough for the PV modules to generate the required cathodic protection current and the excess was stored in the solar battery for use during non-sunshine hours. Values of solar irradiance were taken regularly and also the pipe-soil potentials along both pipelines were closely monitored. After a period of about three months, the specimens buried with the pipes and having electrical contact with the pipes were removed, cleaned and properly washed with 5.0%NaOH, dried and reweighed. Prior to this the initial weights of the specimens were noted. Then the gravimetry technique, Fontana (1986) was used to determine quantitatively the effectiveness of cathodic protection (CP).

3. Results and Discussion

The environmental conditions of each site before and after a period of three months are shown in Tables 1, 2 and 3 respectively.

Table 1: Result of soil analysis before the experiment

Sample	pH	Electrical Conductivity -E.C.(μs/cm)	Electrical Resistivity -E.R. (Ω-cm)
A	5.2	10.0	100000
B	4.6	11.0	90909

Table. 2: Results of soil analysis after the experiment

Sample	pH	E.C.(μs/cm)	E.R. (Ω-cm)
A	5.1	0.0	∞
B	4.0	0.0	∞

Table. 3: Chemical composition of the soil Samples

Sample	% Fe	% Ca	% Mg	% Al
A	0.6011	Trace	0.0326	0.5577
B	0.4933	Trace	0.1306	5.7928

The measurement of soil resistivity has been used for years as an indicator of the corrosivity of soil. Table 4 shows the expected corrosion levels of soils of different resistivity.

The values of the pipe-soil potentials with and without impressed current are shown in Tables 4 and 5.

Table 4: Pipe-soil potentials without impressed current on pipes A and B

d (m)	A (mV)	B (mV)
0.0	-637	-379
0.5	-640	-387
1.0	-640	-395
1.5	-650	-410
2.0	-665	-422
2.5	-677	-429

Table 5: Pipe-Soil potentials with impressed current on Pipe A

d (m)	A (mV)	B (mV)
0.0	-2087	-455
0.5	-1636	-457
1.0	-1282	-459
1.5	-1111	-492
2.0	-1055	-480
2.5	-1080	-500

The rest of the results of the pipe-soil potential along the pipelines are represented in Figs. 2 and 3.

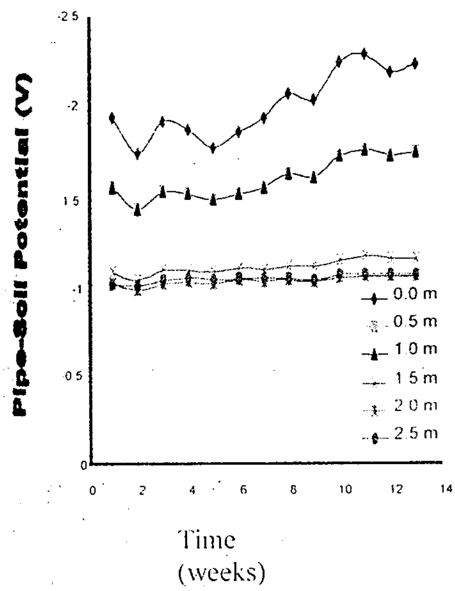

Fig.2. Pipe-soil potential at various distances 0.0 to 2.5 m for the protected pipe A in the Nsukka environment

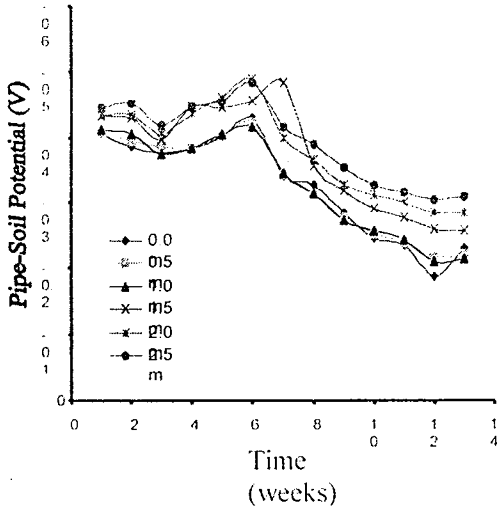

Fig. 3: Pipe-soil potential at various distances 0.0 to 2.5 m for the unprotected pipe B in the Nsukka environment

Figures 4 and 5 show the results of solar irradiance versus time of day in August and October 2002 respectively. It can be seen that the peak sun hours lies between 10.00AM and 2.00PM or approximately four (4) hours of peak sun. It shows that Nigeria is highly endowed with solar energy and thus favorable for PV systems, Figs.4 and 5.

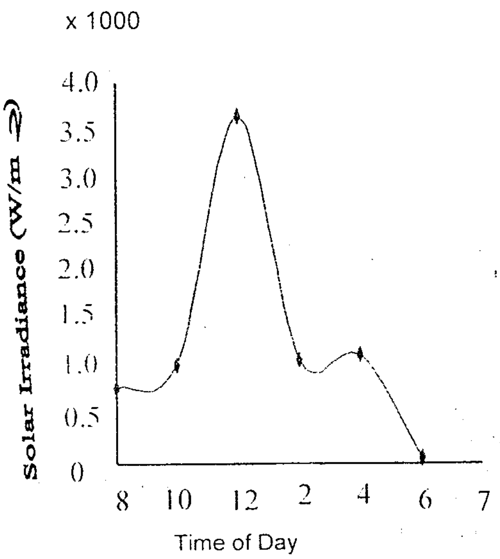

Fig.4: Solar irradiance versus time of day, August 2002

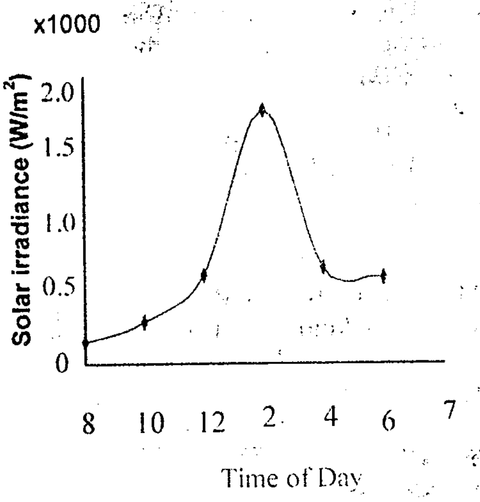

Fig.5: Solar Irradiance versus Time of Day, October 2002

3.1 Pipe-Soil Potential versus Pipe Distance

Fig.6 shows a steady pipe-soil potential for pipe B at the beginning of the experiment also indicating the absence of galvanic cells. By the end of the experiment, the pipe had shown an increase in pipe-soil potential with slight fluctuations, indicating the presence of a few galvanic cells, indicative of slight corrosive activities along the pipeline. Pipe A showed a general trend of pipe-soil potential along the protected pipeline throughout the experiment and indicates absolute protection with a slight decrease in pipe-soil potential at the end of three months.

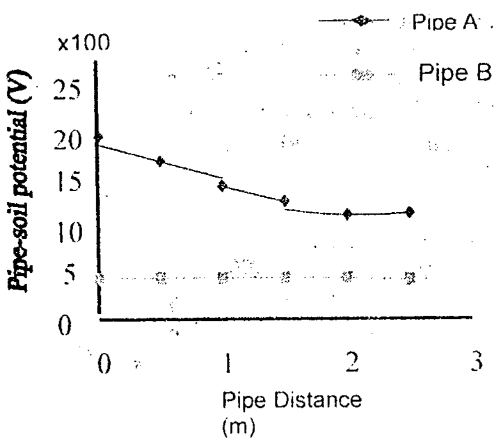

Fig.6: Pipe-soil Potential versus Pipe Distance (Nsukka Environment)

Gravimetry technique is one of the physical methods used to determine quantitatively the effectiveness of cathodic protection (Scp) according to the formula:

$$Scp = \frac{M_o - M_1}{M_o} \times 100\%$$

where M_O = corrosion loss of unprotected steel, M_1 = corrosion loss of cathodically protected steel, Fontana (1986) [12]. For the Nsukka environment, Scp = 75.0% effectiveness of CP for pipe A. The physical characteristics of the pipes are shown in Table 6.

Table VI: Physical characteristics of the pipes and their weights before and after the experiment

Coupon	A	B
Initial Weight (g)	3.06	3.06
Final Weight (g)	3.05	3.02
Weight Loss (g)	0.01	0.04
Length (cm)	2.75	2.75
Width (cm)	2.75	2.75
Area (cm^2)	7.56	7.56
Thickness (cm)	1.00	1.00
Volume (cm^3)	7.56	7.56
Density (g/cm^3)	0.40	0.40
Time (hrs)	4416	4416
Corrosion Rate (mpy)	0.0023	0.0092

The corrosion rate is calculated using the formula:

$$\text{Corrosion rate (mpy)} = \frac{534W}{DAT}$$

where mpy is mils penetration per year ($\mu m yr^{-1}$). W is weight loss (g), D is density (g/cm^3), A is area (cm^2) and T is time (hours), Fontana (1986).

The expected life span, t_x of pipe X, is given by

Pipe X: t_x = pipe thickness / corrosion rate
Pipe A: t_A = 0.5625/ 0.0023 = 244.6 years
Pipe B: t_B = 0.5625/ 0.0092 = 61.1 years

These are the expected life spans of the various pipelines with environmental conditions remaining the same or the soil becoming progressive less corrosive over the years. The minimum acceptable wall thickness under most conditions is 0.4375mm, Duncan (2000).

3.2. Conclusion

The values of the measured soil resistivity increased probably due to the effect of the dry season on the soil and there was a general reduction in the pH values of the sub-soil. An increase in soil resistivity suggests a decrease in the corrosion rate of the pipes. Thus, it was observed that the protected coupon had a lower rate of corrosion than that exposed to attack by the environment. Defining the corrosivity of the environment and implementing corrosion control during the design process for new infrastructure is prudent in ensuring long-term service life. Corrosion control is essential to the efficient long-term performance of capitalized infrastructure in the oil industry. Once a corrosion control program is undertaken, the economic benefits become apparent. Elimination of many pipeline failures and corrosion related equipment failures reduce maintenance costs, and ensures a clean environment and a conducive habitat to plant and animal life. Therefore, when cathodic protection is the right corrosion control method, it has both technical and economic advantages. Southern Cathodic Protection Company (2000).

3.3 References

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