

Cathodic Protection of Buried Steel Oil Pipelines in Niger Delta

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Abstract: Corrosion of metals has been known to be disastrous in industrial setup and even more so in the petroleum industry. Transportation of crude oil, gas and processed petroleum products takes place in pipes, most often steel pipes. Several methods have been used to combat the problem of buried pipeline corrosion among which is cathodic protection. Cathodic protection of a buried steel pipe using zinc anode and a 12 V DC power source has been studied. The experiment was set up in the laboratory for 35 days using moist soil sample from Niger Delta region of Nigeria and weight loss recorded every 7 days. Results show that after 21 days, the protected steel began to lose a very small amount of weight, compared to weight losses for unprotected steel and the anode. A total of 0.04 g of the cathodically protected steel was lost after 35 days compared to a loss of 0.43 g for the unprotected steel. The experiment shows that 90.69% protection was achieved with Cathodic Protection Method of corrosion control. The research demonstrates that buried steel pipes in Niger Delta region of Nigeria can be cathodically protected against failure with very small quantity of electricity. It is recommended that this study be carried out in a soil with high salinity, typical of the Atlantic ocean shore of Niger Delta where several oil pipelines are laid.

Key words: Corrosion, cathodic protection, steel pipe, anode, electrolyte

INTRODUCTION

Corrosion is fundamentally a chemical reaction between a metal and its environment. As such it is a heterogeneous reaction between a fluid and a solid. Corrosion may be caused by chemical reactions with carbonic acid, sulphuric acid or oxygen or by electrochemical metal ion transport hence it is commonly combated inhibitors, resistant alloys, nonmetallic materials or protective coatings (Allen and Raymond, 1990). The failure of oil pipeline can be disastrous both to the environment and the industry. Corrosion of oilfield equipment and piping can lead to potentially hazardous system malfunctions as well as costly damage and repair costs (Akpabio *et al.*, 2011). A recent UK government study estimated that corrosion expenditure amounts to about 4.5% of the turnover of the UK chemical and petrochemical industry. Much of this total expenditure represents investment in materials and protection practices to manage corrosion in new equipment. However, a significant proportion arises from the failure to identify and mitigate well-known corrosion risks at the design stage and the UK study estimated that 15% of the total estimated cost may be saved by the application of existing corrosion prevention technology (Richardson and Cottis, 2006).

With the advent of modern industry, the use of underground metallic structures such as pipelines,

communication cables, well casings and storage facilities became widespread. As the number of underground structures increased, corrosion problems, mainly galvanic corrosion increased, raising the cost of repairs. Now a days even with good protection such as cathodic protection installed, operation personnel are not really aware of the importance of this system. Unfortunately, inspections for corrosion generally are often overlooked until expensive problems such as damaging leaks occur or the corrosion is so prevalent that large areas of the system have to be replaced (Global, 2001). Cathodic protection remains an effective method of mitigating the destructive action of galvanic corrosion.

When two dissimilar metals are electrically connected together such that electrons can flow from one metal to the other it is probable that the anodic, metal dissolution reaction will concentrate on one metal while the cathodic reaction occurs on both. This accelerates the corrosion of the anodic component. The acceleration will be particularly severe if the area of the cathodic metal is much larger than that of the anodic metal. While the anodic metal will corrode more, the cathodic metal will normally corrode less and one form of galvanic corrosion provides a method of corrosion control (known as cathodic protection) in which the anodic, corroding metal is provided deliberately in order to restrict the corrosion of the cathodic metal.

According to Uhlig (1973) corrosion is a naturally occurring physical and chemical deterioration of a material due to reaction with its environment and especially with oxygen. Corrosion is the gradual chemical attack and degradation that results in the conversion of metallic materials into oxides, salts or other compounds. Materials such as metals and its alloys (steel) that have undergone corrosion lose their strength, ductility and other mechanical properties. Corrosion of underground metallic materials is a very widespread problem. Structures such as natural gas and crude oil pipelines and water pipes are some of the structures reported to have been affected by soil corrosion all around the world (Levlin, 1992; Ovri and Ofeke, 1998; Rim-Rukeh and Awatefe, 2006). The failure of gas, crude oil pipeline or water pipe fails is usually accompanied by high degree of environmental, human and economic consequences (Okoroafor, 2004).

The major cause of the deterioration of underground pipeline is the soil. Soil corrosion is caused by moisture, pH, redox potential, microbes in soils and soil type. Underground pipe corrosion can be investigated with Electrical Geophysical Methods such as Electrical Resistivity and Potential Methods (Parasnis, 1986). These methods are used to detect areas of high corrosion (hot spots) along the buried underground pipeline. Once these areas are identified, methods like cathodic protection can be employed to combat the corrosion. Ekine and Emujakporue (2010) successfully delineated such areas in the Niger Delta region. Okah-Avae (1996) described that one of the most popular and widely used methods of protection is by using impressed currents, more commonly called cathodic protection. In cathodic protection of metals against corrosion, an externally applied electric current virtually reduces corrosion to zero and the metal surface can be maintained in a corrosive environment without deterioration for a very long time. The metal structure which would normally be attacked is made cathodic by impressing a reversed current on it.

MATERIALS AND METHODS

Commercial metal samples of steel rod and zinc sheet were obtained from commercial shop by heritage polytechnic main gate. Two lengths of 47 cm each of a steel rod of diameter 2.754 mm was cut and a zinc sheet of 3 cm by 15 cm size was also prepared for the experiment. A 12 V battery and its charger were used for DC supply while an electronic weighing balance (Model: D-46397) was used for weight measurements. Soil samples were collected from a swamp at the campus of Heritage Polytechnic in Niger Delta region of Nigeria into 2 wooden

trough measuring 12,000 cm³ each. One of the steel rods was connected to the negative terminal of DC source, the zinc (anode) connected to positive terminal of the DC source with the aid of copper wires. The steel rod and zinc sheet were then buried in the soil and the DC source was switched on. Another steel rod was buried in the second trough to serve as control. After every 7 days the metal samples were removed from the soil, rinsed with water, oven-dried for 1 h and weighed before being replaced back in the soil. Weight loss was measured over a period of 35 days. The soil samples were watered daily to compensate for loss due to evaporation and also maintain the characteristic moist and swampy soil of Niger Delta. The DC source was checked daily to ensure the required voltage supply.

RESULTS AND DISCUSSION

Results for the experiment are shown in Table 1. Results show that at the end of 7 days, weight loss was recorded for the unprotected steel while the cathodically protected steel did not lose weight. However, after 21 days the protected steel began to show a very small amount of weight loss. While a total weight loss of 0.43 g was recorded for the unprotected steel, only 0.04 g was recorded for the protected steel. A plot of weight loss against number of days is presented in Table 1. Evidently, when dissimilar metals are in contact in the presence of an electrolyte, the more anodic of the two metals is rapidly attacked while the rate of corrosion to the more cathodic metal is retarded. In process equipment this type of association of dissimilar metals is mostly encountered in shell and tube heat exchangers. Also, closely coupling metals with large potential galvanic differences also accelerates corrosion (Lieberman, 1989). Figure 1 shows the likelihood of occurrence of corrosion when various metals are paired for cathodic protection. A general idea of the qualitative risk of bimetallic corrosion can be gained by putting these effects together into a form such as table. This is but a guide to acceptable and potentially dangerous combinations. Actually when discussing cathodic protection of casing, corrosion of the external surface of the well casing occurs due to occurrence of electrochemical cells along the length of the casing. These cells arise due to differences in oxygen levels,

Table 1: Weight loss of materials in grams

Number of days	Weight loss for unprotected steel	Weight loss for protected steel	Weight loss for zinc anode
7	0.28	0.00	0.92
14	0.33	0.00	1.31
21	0.40	0.01	1.98
28	0.42	0.02	2.25
35	0.43	0.04	3.27

■ Additional corrosion unlikely ■ Additional corrosion may occur □ Additional corrosion possible

Metal in contact Metal being considered (a)	Magnesium	Zinc	Aluminium alloys	Carbon steel	Cast iron	Lead	Tin	Austenitic Cast Iron	Brasses	Gunmetals/Tin Bronzes	Copper Nickel alloys	Nickel Aluminium Bronzes	Alloy 400/K-500	Low alloy Stainless Steel	Nickel-Chrome moly alloys	Titanium	High Alloy Stainless Steel	Graphite
Magnesium	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Zinc	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Aluminium alloys	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Carbon Steel	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Cast Iron	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Lead	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Tin	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Austenitic Cast Iron	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Brasses	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Gunmetals/Tin Bronzes	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Copper Nickel alloys	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Nickel Aluminium Bronzes	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Alloy 400/K-500	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Low alloy Stainless Steel	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Nickel-Chrome moly alloys	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Titanium	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
High Alloy Stainless Steel	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Graphite	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Fig. 1: Risk of additional corrosion from bimetallic contact in neutral aqueous electrolyte

different soil strata, temperature variations and locations with poor cementing jobs. Corrosion of casings from these parameters tends to be more severe near the ground surface and in aquifers containing corrosive waters. In cathodic protection system design the quantity of current that must be applied to adequately protect the casing must be known and this can be estimated by E-log tests, corrosion-protection evaluation tool logs and computer simulation. Limitations to cathodic protection include limits on protection depths and interference between welds and across isolating joints.

CONCLUSION

The study clearly demonstrates the ability of cathodic protection method to control corrosion of steel pipes in Niger Delta region of Nigeria. While a total weight loss of 0.43 g was recorded for the unprotected steel, only 0.04 g was recorded for the protected steel. This implies that the method was able to offer 90.69% protection. It is recommended that this study be carried out in a soil with high salinity, typical of the Atlantic ocean shore of Niger Delta where several oil pipelines are laid. Further study on the quantity of electricity required for cathodic protection may improve the quality of corrosion protection.

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