

PROCEEDINGS OF THE NIGERIAN METALLURGICAL SOCIETY

(Peer- Reviewed)

The 34th Annual Conference / Annual General Meetings, Zaira 2018

**Theme: “Exploration and Exploitation of Minerals for
National Development and Sustainability”**

Published by the Nigerian Metallurgical Society, (NMS)

Nigerian Metallurgical Society (NMS)

www.nigerianmetasociety.org

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Paper: NMS 2018-TP027

EFFECTS OF SOLUBLE IONS AND OXYGEN ON THE CORROSION RATE OF BURIED STEEL PIPE IN GIDAN-KWANO, MINNA.

O. J. John^a, A.S. Abdulrahman^b and I.B. Akintunde^b

^aDepartment of Mechanical Engineering, ^bDepartment of Materials and Metallurgical Engineering,

School of Infrastructure, Process Engineering and Technology, Federal University of Technology Minna, Nigeria

Corresponding author: I.B. Akintunde

E-mail address: tundris13@gmail.com

ABSTRACT

The research was conducted to investigate the correlation of soil parameters (soluble Ions and Oxygen) on the corrosion rate of buried low carbon mild steel A106 specification. Six samples were subjected to soil samples gotten from Gidan Kwano Minna, Niger State. Each sample was exhumed with 14 days interval, to study the influence of soil properties towards metal loss via weight loss method with respect to time. The steel samples were buried in the soil, allowed to corrode naturally and then retrieved every 336 hours. The influence of soil soluble ions and oxygen were evaluated using the weight loss method to evaluate the corrosion rate on coupons in the soil. Results showed that that both parameters had an influence on buried steel but soil sulphate had a corrosive influence.

KEYWORDS: Corrosion rate, Soil, low carbon Steel, soluble Ions, Oxygen

1. Introduction

Subsurface pipeline systems are the most reliable, cost-effective and efficient means of transporting massive amounts of liquid and gaseous products. Meanwhile, the buried pipeline system has experienced a considerable number of unforeseen degradation and deterioration resulting to pipeline failure over the years (Hopkins, 2014).

Corrosion has been the main agent of buried pipeline and materials deterioration causing them to fail in service. Albeit, the mechanisms of corrosion has been established from several researches and field studies, but the variation in the formation and type of soil from place to another and regions have varying effects on the corrosion rate of the buried pipeline system, making the prediction of corrosion behaviour of buried metal pipes a challenging area of studies due to the complexity and variation associated with the heterogeneity of soils (Wang *et al.* 2016), conditions where both the chemical

agents and physical structure (gas, liquid and solid phases) are involved (Sancyet *al.* 2010).

Soil has been identified as a key factor affecting corrosion of buried pipes. Reported data showed that soil is responsible for 65% of corrosion of buried pipes (Kreysa & Schütze 2008). The general composition of soils, such as mineral salts and water, are generally considered to be good electrolytes for corrosion (Pritchard *et al.* 2013). Although the corrosion in soil essentially follows the electrochemical theory and appears simple, the analysis in realistic cases is often complicated by the various chemical agents and the complexity associated with the heterogeneity of soils. Hence, it is difficult to correlate the basic electrochemical theory with actual corrosion of buried pipes. Moreover, most of soils parameters such as moisture, temperature and resistivity among others changes spatially and temporally. As a result, soil corrosivity is normally more

difficult to categorize with respect to both surrounding soil parameters and pipe specific properties compared with the corrosivity of atmosphere or seawater (Ferreira *et al.* 2007).

Several researches have been conducted to determine the effects of several influencing factors. Liu *et al.*(2010) investigated the effect of soil compositions (Ca^{2+} , K^+ , SO_4^{2-} , HCO_3^- and NO_3^-), Wuet *al.* (2010) investigated the effect of soil pH (3, 4, 5.5 and 7) on corrosion behavior of metal pipes based on soil simulated soil solutions. The effect of quantity transfer of dissolved oxygen and temperature on corrosion was highlighted based on the work of Nie (Nie *et al.* 2009). However, in most cases, electrochemical parameters derived from soil solution tests were observed differently when compared to field corrosivity tests (Ferreira *et al.* 2007) and hence, the relevance of simulated soil solution tests to replicate the real service soils condition still remains uncertain (Cole and Marney, 2012).

Research on relationship between soil parameters on corrosion rate of carbon steel in Nigeria has not been totally evaluated. Anyanwuet *al.* (2014) conducted research on the correlation between soil properties and external corrosion growth rate of carbon steel in the oil rich southern states of Nigeria. There is an imminent need to study corrosion behavior of buried pipe in other parts of the country, which prompts this research study. This research aims to investigate the relationship between soil parameters on corrosion behavior of buried carbon steels pipe.

2. Materials and method

2.1. Materials

The material for the investigation is a low carbon mild steel A106 specification as received in form of flat sheet, sectioned to dimension (60mm × 40mm × 2mm). The chemical composition of the carbon steel was determined using a spark spectrometric analyzer and the result is presented in Table 1

Table 1: Spark spectrometric analysis of A106 steel sample

Elemental composition	Weight percent (wt. %)
C	0.040
Mn	0.120
Si	0.320
P	0.012
S	0.007
Fe	99.501
Elemental composition	Weight percent (wt. %)

2.2. Methodology

This research study is carried out to determine the effects of soil parameters on the corrosion rate of low carbon steel based on the weight loss method. This method involved subjecting the sample coupons to (soil) medium and measuring the weight loss in the material as a function of time. To evaluate the corrosion rate of the steel pipe, the coupons were buried in the soil dug one meter away from the surface to aid natural corrosion of the samples for a period of one year. However, the samples were exhumed after an interval of two weeks. The initial weight of the coupon was recorded and the final weight after it was exhumed from the ground is also taken. The procedure, preparation and cleaning process of the coupon were followed as stated by the ASTM G01-03.

2.2.1. Specimen Preparation of Soil Sample

The experimental procedures in preparing the soil samples are referred to ASTM G162-99 (Anyanwuet *al.* 2014). The soil samples were collected from six different sites along the GidanKwano, Minna Niger state Nigeria, the soils were first packaged in polyvinyl bags and transferred to the laboratory for determination of its physical and chemical properties.

2.2.2. Soil Sieve Analysis of the Soil Texture

The test was conducted according to ASTM D422. A known weight of dry soil (1000g) was accurately measured, this was transferred into a stack of sieves. The stack sieves was run through a shaker for about 10 to 15 minutes and the amount of soils retained on each sieve was weighed and recorded.

2.2.3. Ion Chromatography Determination of Chloride and Sulfide

The standard procedure was followed during this experiment to determine the level of chloride and sulfate using ion

chromatography which was conducted according to ASTM D 4327.

2.2.4. Oxygen Testing

There are various ways of testing for the level of oxygen within the soil, with different equipment design to run the analysis of oxygen in a given location. For this research Soil Oxygen Meter (SOM) is used to test the level of oxygen in the soil. This instrument uses five ICT soil oxygen sensors which are pin into the soil for the reading to be taken.

2.2.5. Weight loss measurement

Accumulated impurities and corrosion products from the coupons were clean with the aid of brush, after which they were washed with water. After cleaning, the coupons were soaked in acetone for 5-10 minutes and then allowed to dry properly. The initial weight of the sample (W1) and after being exposed to soil environment (W2) was recorded using an electronic weighing scale to determine the corrosion rate. The difference in weight of the sample is most often used as a measure of corrosion or the basis for calculation of the corrosion rate (Anyanwuet *al.* 2014).

$$W = W_1 - W_2 \quad (1)$$

Where, W = weight loss, W1=initial weight, W2= final weight after exposing to soil

Determination of Corrosion Rate

The surface area of each coupon was calculated using:

$$A = 2 \times [(L \times B + B \times T + L \times T)] \quad (2)$$

Where, L = Length of the coupon, B = Width of the coupon and T = Thickness of the coupon. The weight loss of the coupons which were used to compute the corrosion rates of the coupons was measured using the KERRO BLG 2000 electronic scale having a precision of upto 0.01gm. Hence the corrosion rate was computed using the formula:

$$\text{Corrosion rate (mmps)} = \frac{9.7 \times \text{Weight Loss}}{\text{Area} \times \text{Time} \times \text{Density}} = 3$$

Where: W = weight loss in milligrams, A= area of coupon, T = time of exposure of coupon in hours
 ρ = density of steel (Anyanwuet *al.* 2014).

3. Result and Discussion

3.1. Elements of Soil

Majorly, soil constituents and parameters dictate the corrosion rate of buried steel pipe due to the total exposure to the medium. This pipe soil medium corrosion attack is the most severe failure mechanisms experienced by buried steel pipelines (Widdel, 1988). In general, soil parameters comprise pH, moisture, sulphates, resistivity, chlorides and aeration (Nivens *et al.* 1986). Soil containing large concentration of soluble salts in the form sulphates, chlorides, porosity (aeration), electrical conductivity or resistivity, moisture and pH are the most corrosive soils (Widdel, 1988; Nivens *et al.* 1986).

3.2. Weight Loss of Samples

The coupons A-1, A-2, A-3, A-4, A-5 and A-6 were exposed to the soil over a period

of 336, 672, 1008, 1344, 1680 and 2016 exposure hours respectively. The initial weight of each coupon was measured and recorded using a digital weighing scale. The final weight of the coupon was also recorded after it has been exhumed from the soil. The loss of weight is the differences between the initial and the final weight of the coupon. The weight loss per area is the division of the weight over the surface area of the coupon.

As the exposure time increases, the weight loss also increases, showing a linear progressive straight line. This meaning that the longer the coupon stay within the soil the more tendency the material corrode indicating that the presence of soil oxygen and soluble ion, enhance the surface disintegrate of the sample. The gradient of the straight line is less than one showing a gradual disintegration of the material. The coupon will continue to corrode at this rate if the condition remains unchanged.

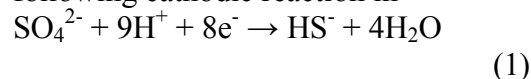
Table 2: Evaluation of A106 steel sample results

Coupon	Hours	Initial weight	Final Weight	Weight Loss	Corrosion Rate (g/cm ² /hr.) x10 ⁻²	Corrosion Rate/area (g/hr)x10 ⁻³	Corrosion Rate/area/hr. (g) x 10 ⁻⁶
1	336	38.6	38.5	0.1	6.2	1.19	3.55
2	672	39.8	39.6	0.2	6.1	1.17	1.75
3	1008	41.1	40.6	0.5	9.8	1.89	1.87
4	1344	40.4	39.8	0.6	8.9	1.71	1.27
5	1680	43.3	42.4	0.9	10.0	1.92	1.15
6	2016	39.6	38.5	1.1	11.1	2.14	1.06

3.3. Effects of Sulphates ions

Sulphates are more corrosive toward metallic materials than chloride in poorly aerated soils. Sulfate concentration is 2000 ppm or greater represent corrosive condition. These ions are major nutrients to Sulfate Reducing Bacteria (SRBs); facultative anaerobes normally found in soils located near buried pipelines and are a

major biological contributor to MIC that produce highest rate of corrosion (Zhang *et al.* 1987). SRB utilize sulphate as a terminal electron acceptor during energy generation, producing sulphide as a by-product by the following cathodic reaction in



The HS^- as product of reduction of sulfate anions typically will interact with the ferrous iron, produced by the anodic reaction, to give FeS , rather than $\text{Fe}(\text{OH})_2$,

which is evident by the black encrustations which occur around steel subjected to Microbial Induced Corrosion (MIC) (Zhang *et al.* 1987).

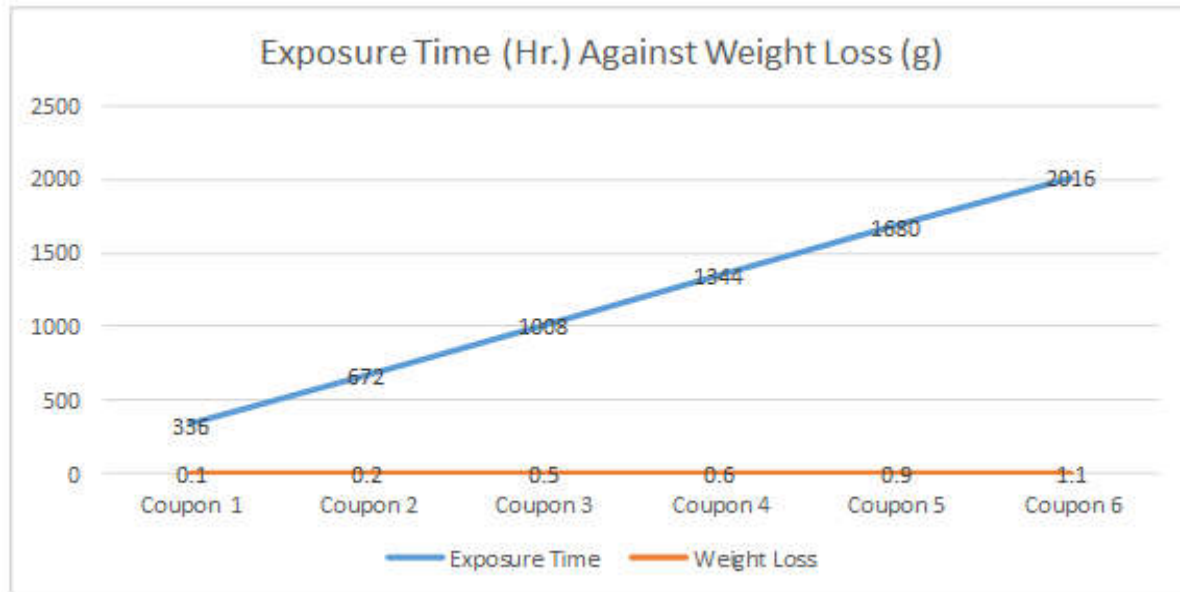


Figure1: Weight loss against exposure time

3.4. Effects of Chlorides ions

Chloride is found naturally in soils as a result of brackish groundwater, historical geological sea beds, and from external sources such as de-icing salts applied to roadways. This proves that the corrosion rate of steel pipes buried along GidanKwano Minna Niger State Nigeria will be supported by the presence of Cl^- . The corrosion rate is enhanced by the presence of chloride ion concentration of 1.0% and the corrosion rate of the steel in soils becomes aggressive when the chloride concentration exceeded 2.0% (Fanget *al.* 2008, Zhanget *al.* 2000).

3.5. Oxygen

Oxygen concentrations are decreased with increasing of soil depth. Oxygen concentration has important effect on corrosion rate either in alkaline or neutral soils as a result of reaction in cathodic reaction. Oxygen supply is higher in coarse-

textured, dry soils than in fine and waterlogged textures. Since soil consisted of soil grains and pores, it is reasonable that the contact interface of steel and soil may exhibit an image of such that the locations where the steel surface closely contacts with soil grain should be in a situation of low oxygen concentration, however other locations where the steel surface contacts a pore or pores should be in a situation of higher oxygen concentration (Ivet *al.* 1984). As it is well known that sulfate may be reduced to sulfide, such as H_2S and FeS , by SRB via sulfate as an electron acceptor in an anaerobic environment. A location where FeS accumulated can act as a cathode on the surface of steel, and then new corrosion cells would form.

Conclusion

This research investigates the effects of soluble ions and oxygen on the corrosion

rate of steel in soil environment. Pipeline corrosion is extremely complicated and is effected by practically every physical, chemical, and biological parameter in water distribution systems. Though soil soluble ions speed up the rate of corrosion, sulphate ions was found to have greater influence. Furthermore, corrosion rate of steel buried underground is also time dependent.

Acknowledgements

The authors wish to recognise the support of the Science & Technical Education at Post-Basic Levels (STEPB).

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