EFFECT OF SOIL pH ON CORROSION OF MILD STEEL AND HIGH CARBON STEEL IN MINNA

DIM, P.E.[1], MUSA, J. J.[2*], ONUKWULI, O. D.[3] and ADAMA, K. K.[4].

1. Department of Chemical Engineering, Federal University of Technology, Minna, Nigeria. Email: pevdim@yahoo.com
2. Department of Agricultural & Bioresources Engineering, Federal University of Technology, Minna, Nigeria. Email: jogric2000@yahoo.com*
3. Department of Chemical Engineering, Nnamdi Azikiwe University, Awka, Nigeria, Email: onukwuliod@yahoo.com
4. Advanced Laboratories, Sheda Science and Technology Complex (SHESTCO), P M B 186 Garki, SHEDA, Nigeria. Email: kenpriestly@yahoo.com

* Corresponding author

ABSTRACT

A long term underground corrosion of mild steel and high carbon steel was investigated at two location; a dry land (site A) and wet land (site B) at Gidan Kwano village, Minna. In the tests, nonradioactive metal metals namely mild steel and high carbon steel were buried at the disposal location. The investigation was carried out at soil depth ranging between 0.2 m and 0.6 m with pH varying between 6.0 and 8.3. The soil samples were treated with calcium chloride ($CaCl_2$), sulphuric acid (H_2SO_4) and sodium hydroxide (NaOH) solutions. The results of corrosion analysis from metals exposed underground for five months showed that the rate of pits and crevices formation observed at site A was higher at a depth of 0.6 m for mild steel and high carbon steel, respectively. The maximum rate of pits and crevices formation at depth of 0.6 m in site A was due to lack of oxygen which favoured the activities of anaerobic bacteria while in site B pitting and crevices were more pronounced at depth of 0.2 m due to the presence of oxygen and moisture. It was concluded that mild steel corrodes about three times faster than high carbon steel.

Keywords: Carbon steel, Crevices, Corrosion, Mild steel, Pits, Soil

INTRODUCTION

Metal pipes have been used to transport potable water for over 500 years and iron pipe corrosion has been a problem for just as long. Iron corrosion is an extremely complex process. Because of the large variability in distribution system conditions, a particular factor may be critical in one system but relatively unimportant in another system. Moreover, corrosion itself has several different manifestations and can be evaluated in many ways. Previous studies on pipe corrosion have focused on different aspects of corrosion: pipe degradation (measured by weight loss, oxygen consumption or corrosion current), scale formation (measured by head loss or scale deposition), and by-product release (Tétreault *et al.*, 2003).Corrosion is the gradual physico-chemical destruction or alteration of material through the chemical action of its environment (Tretheway and Chamberlain, 1992). Corrosion is a phenomenon that affects almost all non-metals and metals. From ancient times the phenomenon of corrosion has been observed and noted such as high resistance of gold to corrosion, the resistance of benzene to salt environment and that of lead to rain water and potable water (Kull *et al.*, 2006). In many areas, soil encountered along pipe line routes is almost neutral (pH of 7). Mild steel is widely used in pipes buried in soil. The rate of corrosion penetration depends on the corrosiveness and non - corrosiveness of a particular soil and other factors including variation of concentration of dissolved matters in the soil water and alkalinity of the soil. Laboratory investigations are highly important but require the knowledge of physical and chemical properties of the soil which can be affected by many factors, particularly by changes in the nature of the soil (Sarin *et al.*, 2001). Observation show that steel in de-aerated, dry soil should not corrode at all but most soils are not dry. The susceptibility of materials to rapid corrosion in underground condition places severe limitations on the use of such materials for fabrication of subsurface facilities such as fluid storage tanks and pipelines (Niklasson *et al.*, 2004).

Corrosion is caused by a flow of electricity from one metal to another or a recipient of some kind; or from one part of the same metal when condition permits the flow of electricity (Denisov *et al.*, 1981). Before corrosion can take place the following conditions must exist. (1) The presence of anode and cathode, (2) electrical potential between the anode and (3) cathode and metallic path electricity connecting the anode and cathode which in most cases is the moisture or water surrounding the metal such that electric current flow between metals will be consumed at the anode (Kammar, 2000). Corrosion control consists of one or more measures such as material selection, inhibition, painting, cathodic protection, and special design feature.

Corrosion can be broadly classified into two types depending on the mechanism of the control process. There are chemical corrosion otherwise called dry corrosion and electrochemical corrosion also called wet corrosion. Chemical refers to those that are not accompanied by generation of electric current. It can further be divided into: gaseous corrosion involving corrosion of metals in the complete absence of moisture under high temperature oxidation and corrosion in non-electrolytes which refers to substances that do not posses significant electrical conductivity such as corrosion of iron in sulphur containing naphtha at elevated temperature. Electrical corrosion refers generally to the corrosion of metals in electrolytes. It occurs with generation of current with different types of electrochemical corrosion damage (Eisnor and Gagnon, 2004).

The objectives of the this study are to determine the potency of attack of Gidan Kwano soil on mild steel and high carbon steel and to compare the rate of corrosion of mild steel and high carbon steel.

METHODOLOGY

Site preparation

Two sites were chosen, site A (a dry land) and site B (a location at a reasonable distance away from a flowing stream). Both sites are in Gidan-Kwano village. At each site the soil was dug out to a depth ranging from 0.2 m to 0.6 m with a diameter of 45 cm enough to accommodate two specimens at a time and at a distance of 20 m apart. Each metal was buried by positioning it in such a manner that both sides of the metal piece were adequately exposed to the same conditions. The metals were arranged by positioning them standing on their edges. However, few selected controls were buried, placing the metal horizontally in the hole. The holes were then covered (refilled) with the dugout soil and the surface of the holes compressed to air tight and left for the required period of time. The masses of the metals were recorded before burying and the final masses were recorded after successive committing of pitting, filling and brushing.

The pH of the soil in each of the sites was determined through laboratory analysis constantly to maintain a range of between 6.0 and 8.3.The metals were buried for a total of five months but were exhumed for examination at an interval of one month. The exhumed metals were washed with water to remove the adherent corrosion product. The surfaces of the metal were then carefully inspected for pit formation using a microscope with powerful lens. Pits were identified and counted and after visual microscopic observations, the metals were reburied at the same soil depth for another month. However, before each metal was buried, the soil pH was measured.

Specimen preparation

The materials used for the investigation are mild steel and high carbon steel in sheet form (12mm gauge). The individual sheet was cut into small rectangular specimens of dimensions 3 cm by 5 cm by 0.4 cm using a cutting machine and file to smoothen the edges. The cut specimens were thoroughly brushed using iron brush after which they were sand papered, then washed with detergent to free the metal surface of rust and other dirt's and immersed in lubricating oil to avoid atmospheric corrosion. Metals are pieces of materials buried in the environment to corrode and are analysed to determine the rate of corrosion.

Measurement of soil pH

The soil samples were collected at each depth and at each of the locations. Sixty grammes of soil from each depth was added to 50 ml of distilled water and the pH was determined using a pH meter. This procedure was repeated at intervals of 30 days and adjustment was done by mixing soil with calcium chloride and soda lime solution and mixture of soda lime and sulphuric acid.

RESULTS

Presented below are the results obtained from the two sites (wet and dry soils) for the two types of metals considered for this study. Table 1 presents the results of mild steel in dry soil; Table 2 presents the results of mild steel in wet soil while Tables 3 and 4 present the results of carbon steel in dry an

Table 1: Result of experiment conducted on site A (dry soil) for mild steel

Specimen No	Depth of soil (m)	pH of soil and additive	Initial mass of specimen (g)	Initial Pits formed	Duration of burial (day)						Rate of pit formation	Final mass (g)	Rate of corrosion (g)
					30	60	90	120	150	Tp			
1	0.20	7.2 (NA)	26	NP	0	3	5	7	12	27	0.0120	24.50	0.00067
2	0.20	6.1 (CaCl2)	26	NP	0	4	7	9	24	44	0.0196	21.30	0.00209
3	0.20	6.1 (H2SO4 + NaOH)	26	NP	0	6	10	15	19	50	0.0222	19.20	0.00302
4	0.40	7.4 (NA)	26	NP	0	0	7	12	18	37	0.0164	22.50	0.00156
5	0.40	6.6 (CaCl2)	26	NP	0	6	12	16	54	88	0.0391	17.30	0.00387
6	0.40	8.3 (H2SO4 +NaOH)	26	NP	0	4	6	8	28	46	0.0204	21.00	0.00222
7	0.60	7.2 (NA)	26	NP	0	0	0	8	32	40	0.0178	22.00	0.00178
8	0.60	6.8 (CaCl2)	26	NP	0	0	7	25	72	104	0.0462	15.80	0.00453
9	0.60	7.3 (H2SO4 +NaOH)	26	NP	0	5	8	24	52	89	0.0396	17.00	0.00400

Table 2: Result of Experiment on Site B Mild Steel in Wet Soil

Specimen No	Depth of soil (m)	pH of soil and additive	Initial mass of specimen (g)	Initial Pits formed	Duration of burial (day)						Rate of pit formation	Final mass (g)	Rate of corrosion (g)
					30	60	90	120	150	Tp			
1	0.20	7.2 (NA)	26	NP	0	0	0	0	0	0	0.0000	25.00	0.00044
2	0.20	6.1 (CaCl2)	26	NP	0	0	2	3	4	9	0.0040	22.00	0.00178
3	0.20	6.1 (H2SO4 + NaOH)	26	NP	0	0	0	1	3	4	0.0018	23.00	0.00133
4	0.40	7.4 (NA)	26	NP	0	0	0	0	2	2	0.0009	24.00	0.00089
5	0.40	6.6 (CaCl2)	26	NP	0	0	3	4	1	8	0.0036	22.50	0.00156
6	0.40	8.3 (H2SO4 +NaOH)	26	NP	0	0	0	2	4	6	0.0027	24.00	0.00089
7	0.60	7.2 (NA)	26	NP	0	0	0	1	3	4	0.0018	23.00	0.00133
8	0.60	6.8 (CaCl2)	26	NP	0	0	3	3	6	12	0.0053	21.50	0.00200
9	0.60	7.3 (H2SO4 +NaOH)	26	NP	0	0	0	1	5	6	0.0027	24.10	0.00084

Table 4: Result of Experiment on Site B for Carbon Steel (Wet Soil)

Specimen No	Depth of soil (m)	pH of soil and additive	Initial mass of specimen (g)	Initial Pits formed	Duration of burial (day)					Tp	Rate of pit formation	Final mass (g)	Rate of corrosion (g)
					30	60	90	120	150				
1	0.20	7.2 (NA)	26	NP	0	5	8	15	18	46	0.0204	23.40	0.00116
2	0.20	6.7 (CaCl2)	26	NP	0	9	14	24	32	79	0.0351	21.20	0.00213
3	0.20	7.2 (H2SO4 + NaOH)	26	NP	0	10	15	17	23	65	0.0289	22.50	0.00156
4	0.40	6.1 (NA)	26	NP	0	8	13	16	18	55	0.0244	22.00	0.00178
5	0.40	6.3 (CaCl2)	26	NP	0	6	15	23	24	68	0.0302	20.50	0.00244
6	0.40	7.5 (H2SO4 +NaOH)	26	NP	0	5	8	8	17	38	0.0169	18.50	0.00333
7	0.60	6.1 (NA)	26	NP	0	4	6	9	11	30	0.0133	17.50	0.00378
8	0.60	6.3 (CaCl2)	26	NP	0	3	8	14	16	41	0.0182	18.00	0.00356
9	0.60	7.7 (H2SO4 +NaOH)	26	NP	0	6	9	10	13	38	0.0169	19.50	0.00289

Where

NP means Number of pits formed

Tp is the total number of pits formed at the end of the five months.

Discussion of Results

Soil can be described as a medium through which various agricultural and construction activities are carried out or are allowed to take place. Such agricultural activities include the laying of pipes for irrigation activities. The pipes are usually placed in the soil at specified depth depending on the soil type and the type of crop to be planted on such fields. This necessitated the study of the effect of pH on the corrosive nature of mild and high carbon steels in Gidan Kwano area of Niger state.

It was observed that the rate of corrosion for mild steel increased with depth from 0.2 m to 0.6 m in dry soil and decreased with depth from 0.2 m to 0.6 m in wet soil. This is as a result of aerobic bacterial activities on digging out and refilling of holes. In dry soil the rate of pitting is higher at the 0.6 m and lower at 0.6 m because the soil is compacted at this depth and aerobic bacterial activities are low. Tables 3 and 4 show similar trend, the difference is that the pitting formed is higher in mild steel than carbon steel due to the high carbon content in the carbon steel. It was observed from

Table 1 that no pits were formed in the first 30 days of which the mild steel was buried at a depth of 0.20 m but as the days of burying increased the number of pits formed on the mild steel increased. A sharp increase was observed at a depth of 0.40 m at the end of 150 days of burying. Fifty-four pits were counted with the rate of pit and corrosion formation given as 0.0391 and 0.00387 g, respectively. Though, the soil at this stage was treated with Calcium chloride to keep the power of hydrogen (pH) within the neutral range and the higher rate of pit formation may be because of the anaerobic action that took place thus increasing the number of pit formation. More so, the chemicals added might have reacted with already existing chemical fertilizers and herbicides within the soil which might have increased the rate of pit formation and corrosive actions.

The rate of corrosion was observed to be highest at the depth of 0.60 m and also at the same depth a corrosion rate of 0.0462 g of pit formation was observed. Using the same mild steel but varying the soil condition (wet soil); it was observed that from Table 2 that during the first 60 days the metal was buried no pit formation was observed. At the end of the 90th day of burial, the metal at 0.20 m had only 2 numbers of pit formation seen and at the end of 150 days of burying the metal only 4 pits were formed. The rate of pit formation here was calculated to be 0.0040 g and the rate of corrosion was also calculated to be 0.00178 g while the total mass lost was 4 g. At the depth of 0.60 m it was observed on the 90th day that only 3 numbers of pits were formed and at the end of the 150th day 6 numbers of pits were formed. A total number of 12 pits were formed making it the highest number of pits to be formed while the rates of pit and corrosion activity were 0.0053 and 0.00200, respectively. This further proved that there is a high chemical concentration at the region and also a possible impervious layer of soil which have not allowed the filtration of these chemical to other areas below this level. Results presented in Tables 3 and 4 were not much different from the previous Tables of 1and 2. At a depth of 0.20 m, a total number of 79 pits were formed at the end of five months which was found to be the highest at this level of 0.20 m. The rate of pit and corrosive actions were calculated to be 0.0315 and 0.0023, respectively and the mass lost at this stage was 4.8 g. It was observed that aerobic bacterial activities is higher at the top of the wet soil which gives rise to more oxygen formation at this region thereby increasing the rate of pitting formation but in the dry soil the bacterial activity is higher at the depth of 0.6 m.

Conclusions

Corrosion of mild steel and high carbon steel buried at depths ranging between 0.20 m and 0.60 m was studied at the soil condition of pH of 6.0-8.3. Under these conditions corrosion does not commence in mild steel specimen until after an initial period of one month thereafter, corrosion rate increases at the third and fourth months and rapid at fifth month for soils that are approximately neutral (pH 6.6 to 6.80) which favoured pitting rate in mild steel while increasing in alkalinity or acidity of the soil tend to inhibit spreading in the materials. Mild steel with one third of carbon content of high carbon steel corrode faster than high carbon steel under the same underground conditions. This suggests that the rate of corrosion of mild steel and high carbon steel is inversely proportional to their carbon content. This can be used as a useful expression to predict underground corrosion rate of mild steel and high carbon steel. The expression is important in estimating the service life of steel plant equipment and structures in underground conditions.

Recommendations

Engineers and Technicians intending to install steel plants equipment for agricultural and other structural activities as underground working tools at Gidan Kwano should make sure that conditions necessary to enhance corrosion as this study has revealed must be taken into consideration. Soil samples at various depths and locations must be critically analysed to investigate anions (e.g. chloride ions which provide aggressive environment for steel corrosion to occur) and installation should be avoided where these anions are found. Any soil whose pH is acidic or slightly acidic should either be avoided or reconditioned to pH of slight alkalinity.

Corrosion rate of steel depends on their carbon content, it is important that steel which is meant to be installed underground should be made of relatively higher percentage of carbon in order to appreciably reduce the rate of corrosion.

REFERENCES

Denisov, G.V. Kovrov, B.G. and Kovaleva, T. F. (1981). Effect of the pH and Temperature of the Medium on the Rate of Oxidation of Fe^{2+} to Fe^{3+} by a Culture of Thiobacillus ferrooxidans and the Coefficient of Efficiency of Biosynthesis (Translated from Russian). *Mikrobiologiya (Microbiology),* 50:5:696 (1981)

Eisnor, J.D., Gagnon, G.A. (2004). Impact of secondary disinfection on corrosion in a model water distribution system. J. Water Supply Res. Technol.—Aqua 53 (7), 441–452.

Kammar M.C. (2000). Basic principle of corrosion paper presented at the work shop on corrosion prevention on management in engineering infrastructure held at Lagos on 10th may 2000 page 3-20

Kull, T.P.J., Sjoevall, O.T., Tammenkoski, M.K., Backlund, P.H., Meriluoto, J.A.O. (2006) Oxidation of the cyanobacterial hepatotoxin microcystin-LR by chlorine dioxide: influence of natural organic matter. Environ. Sci. Technol. 40 (5), 1504–1510.

Niklasson, A., Johansson, J. E., and Svensson, L. G. (2004). Atmospheric corrosion of historical organ pipes: influence of acetic and formic acid vapour and water leaching on lead. Proceedings of Metal 2004 National Museum of Australia Canberra ACT. Pg 273 - 280

Sarin, P., Snoeyink, V.L., Bebee, J., Kriven, W.M., Clement, J.A. (2001). Physico-chemical characteristics of corrosion scales in old iron pipes. Water Res. 35 (12), 2961–2969.

Tretheway, K. K. and Chamberlain, J. (1992) Corrosion for students of science and Engineering long man scientific and technical essex, England, page 124-145.

Tétreault, J., Cano, E., van Bommel, M., Scott, D., Dennis, M., Barthés-Labrousse, M.-G., Minel, L., Robbiola, L. (2003) *Corrosion of copper and lead by formaldehyde, formic and acetic acid vapours*, Studies in Conservation, 48, 4, 237-250