Relationship between Soil Properties and Corrosion of Steel Pipe in Alkaline Soils

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***Abstract*-This paper investigates the relationship between soil properties and corrosion of low carbon steel pipe in three different soils. The study focuses on major soil properties such as soil resistivity, soil moisture content, soil redox potential, and chloride, sulphate, bicarbonate contents. The steel pipe specimens were dipped into 3 different soils for 7 months and after 7 months of soil exposure the relationship soil properties and corrosion rate of steel pipe plotted and analyzed.**

Keywords: Soil Corrosion, Soil Properties, Soil chemistry Corrosion relationship, Polarization

I. INTRODUCTION

Corrosion is defined as degradation of material or its properties due to a reaction with environment. Soil corrosion is a complex phenomenon with number of factors involved. Soil corrosion as deterioration of metal or other material brought about by chemical, mechanical and biological action by the soil environment. [8]

The corrosion of ferrous metal in soil is a major problem for distribution of water, sewage, oil and gas system. The most common corrosion failure mechanism for buried ferrous pipe is localized corrosion leading to leaking. [1] The pipeline corrosion is most prevalent when breakdown of coating, inhibitors or cathodic protection take place in corrosive environment. Author proposed the model with seven stages of corrosion life. These seven stages consist of Pit nucleation, Pit growth, transition from pitting to fatigue crack nucleation, short crack growth and transition from short crack to long crack, long crack growth and failure. [2]

The common types of corrosion that can occur in a buried pipe are:-

- Pitting corrosion owing to material inhomogeneities.
- Chloride and sulphate induced stress corrosion cracking
- Corrosion by concentration cell in soil arising out of difference in oxygen concentration in soil adjacent to the pipe at different region.
- Microbiologically induced corrosion under anaerobic condition by sulphate reducing bacteria and acid forming bacteria.[2]

The soil engineering properties and soil content are important parameter that influences the soil corrosivity and level of corrosion dynamics these are namely Soil resistivity, Soil pH Soil redox potential, Soil temperature, Soil content ,Liquid limit , Plastic limit, Soil chemical content etc.[8,5,15]

II. EXPERIMENTAL

2.1 Materials and Methods

It has been aimed to investigate corrosion performance of buried pipeline. Therefore material selected for this study is commercially used Mild Steel pipe having chemical composition as shown in table 1.

Table 1 - Chemical composition of MS pipe used for corrosion study

Elements	C	Mn	Si	S	P	Fe
Wt. %	0.040	0.12	0.032	0.007	0.012	Balance

2.2 Soil collection

Soil samples for the study collected from three different locations covering approximately 20 km distance. At each of selected locations the soil samples were collected by digging a hole of 0.5 m deep. Soil sample will be collected from each sites and kept in polyethylene bags before sent to the laboratory for further soil analysis.

2.3 Soil analysis

The collected soil samples were tested for soil corrosivity properties such as soil resistivity, soil redox potential, soil pH, soil moisture contents in a laboratory as per IS 2720 Standard and soil chemical composition in which chloride contents (Cl^-) as per APHA 4500-Cl-B, soluble bicarbonate (HCO_3^-) as per APHA 2320 B, Sulphate contents (SO_4^{--})as per IS 3035 (Part 24) and Nitrite contents as per IS 3035 (Part 34).

The moisture content of soil sample was calculated using weight loss technique as per IS 2720 (Part 2). For this a 30 gm of each soil sample is dried in a drying oven at 110 ^{0}C for 24 hrs. The weight difference between sample before and after evaporation is regarded as the moisture content. [2]

The soil redox potential was measured by a multimeter, Pt electrodes and a saturated calomel electrode (SCE). The redox potential was calculated by the following relationship:

$$Eh = Em + 250 + 60 \times (pH - 7)$$

Where Eh=Redox potential at pH=7 (mV, standard hydrogen scale); Em=mean of the potential measured from the platinum electrode (mV).

2.4 Material preparation / cutting

Steel pipe specimens were cut from original pipe each having 25.4 mm outer diameter 2 mm thickness and 20 mm length.

2.5 Specimen's installation in soil

Prepared steel pipe specimens were kept in each soil sample in order to check their corrosion behavior in soil environment. Triplicate specimens were removed after every month from collected soil samples for corrosion test and their characterization.

2.6 Cleaning

Two cleaning methods were used to remove the impurities of the coupons, namely mechanical and chemical cleaning. The mechanical cleaning was carried out to remove the soil particles on the surface of samples using a soft brush. It was then followed by ultrasonic cleaning whereby the samples were immersed in distilled water for the period of 15 min.

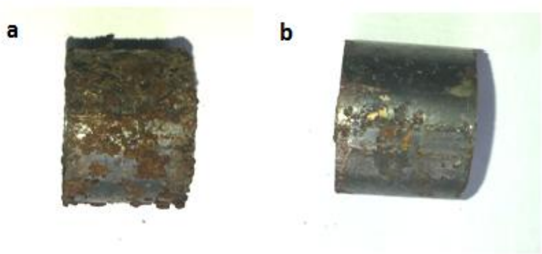

Fig. 1 - Pipe specimen (a) before cleaning (b) after cleaning

2.7 Corrosion studies

A conventional three electrode cell was used with Stainless steel plate as counter electrode, Saturated Calomel Electrode SCE is used as reference electrode, steel pipe specimens as a working electrode and electrolyte in 3.5 wt. % NaCl solution. Tafel polarization test were performed on steel pipe specimens, which are immersed in three different soil medium, after 7 month of immersion on Gamry potentiostat instrument (Reference 600) at a scan rate of 1 mV/s. Specimens for electrochemical tests were made from steel pipe whose chemical composition was shown in table. The corroded steel pipe samples were cut into tests specimen with dimensions of 17 mm × 20 mm and then covered with epoxy resin except test surface with the working area of 3.4 cm^2.

III. RESULTS AND DISCUSSION

3.1 Properties and composition of soil used for corrosion test

The collected soil samples are tested to check corrosivity properties of soil such as soil resistivity, moisture content, redox potential , pH etc as per IS 2720 and results are shown in table 2 and chemical composition of three different soils obtained from soil laboratory test is shown in table 3.

Table 2 - Properties of collected three different soil samples

Properties	**Soil 1**	**Soil 2**	**Soil 3**
Moisture content (%)	45.59	40.93	30.20
pH	8.45	8.36	8.32
Rating	Moderately alkaline	Moderately alkaline	Moderately alkaline
Electrical conductivity (dS/m)	0.30	0.25	0.10
Resistivity (Ω cm)	3300	4000	10000
Redox potential (mV)	329.64	332.06	337.44
Texture class	Sandy loam	Clay	Sandy loam
Sand (%)	58.90	33.37	67.15
Silt (%)	25.50	24.33	15.37
Clay (%)	14.40	41.30	16.28

Table 3 - Chemical composition of three different soils

Content (g/kg)	Cl^-	SO_4^{--}	NO_3^-	$HCO3^-$	Ca^{++}	Mg^{++}	Na^+	K^+
Soil 1	0.117	0.200	0.144	0.538	5.84	2.81	2.89	7.12
Soil 2	0.067	0.063	0.100	0.359	12.32	1.48	2.34	11.75
Soil 3	0.060	0.045	0.063	0.001	9.60	1.64	1.70	10.60

3.2 Potentiodynamic polarization studies

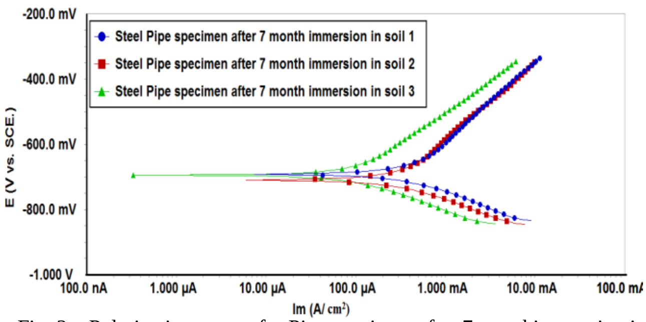

Fig. 2 – Polarization curves for Pipe specimen after 7 monthimmersion in three different soils

Fig. 2 Shows potentiodynamic polarization curves for the steel pipe specimens which are immersed in three different soils. The corrosion rate of specimen after 7 months of soil exposure in soil 1 soil 2 and soil 3 are 64.21 mpy, 55.22 mpy and 16.35 mpy respectively. It has been observed that the steel pipe specimen which was immersed in soil 1 have more rate of corrosion than others.

The soil properties responsible for corrosion of steel pipe is analyzed based on corrosion rate of steel pipe after 7 month immersion in respective soils and their relationship plotted as discussed below.

3.3 Soil Resistivity

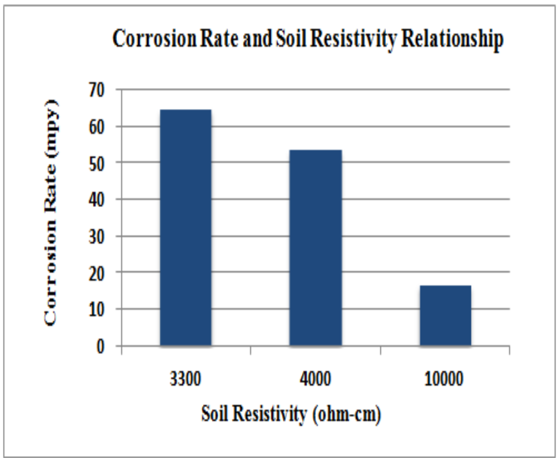

Fig. 3 - Relationship between corrosion rate and soil resistivity

Soil resistivity is a measure of ability of soil to conduct a current. Fig. 3 shows relationship between resistivity of three different soils and corrosion rate after 7 month immersion in respective soil. The highest resistivity value was measured for soil sample 3 while soil sample 1 has lower resistivity value. There is no big difference in resistivity value of soil sample 1 and soil sample 2. The steel pipe specimen immersed in soil and after 7 month immersion corrosion rate is measured and compared with soil resistivity property. It has been found that with increasing the resistivity of soil, corrosion rate decreases. The soil with highest value of resistivity that is 10000 Ω cm has very low rate of corrosion 16.35 mpy compared to soil 1 and soil 2 having resistivity value 3300 Ω cm and 4000 Ω cm and corrosion rate 64.21 mpy , 53.22 mpy respectively. Also the soil with lower resistivity linked to high water content and high salt concentration that is chloride and sulphate in case of soil 1 and lower moisture content and salt concentration corresponds to higher resistivity in case of soil 3.

3.4 Soil Moisture Content

The liquid represent the essential electrolyte required for electrochemical corrosion reaction. Fig .4 shows relationship between soil moisture content and corrosion rate of steel pipe after 7 month immersion in soil.

The moisture content of soil 1, soil 2 and soil 3 are in order of 45.59 %, 40.93 % and 30.20% accordingly corrosion rate 64.21 mpy, 53.22 mpy, 16.35 mpy respectively. It has been seen that soil with highest moisture content has high value of corrosion rate than the soil with low moisture content.

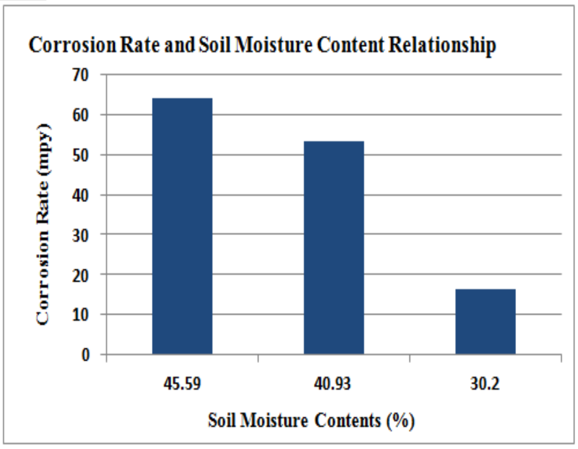

Fig. 4 - Relationship between Corrosion Rate and Soil moisture content.

3.5 Soil Redox Potential

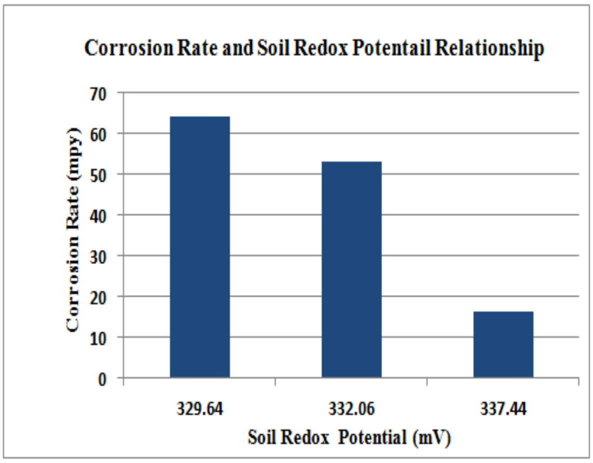

Fig. 5 - Relationship between Corrosion rate and Soil Redox Potential

Fig. 5 shows relationship between soil redox potential and corrosion rate of steel pipe after 7 month immersion in respective soil. The redox potential and corrosion rate of soil 1, soil 2 and soil 3 are 329.64 mV, 332.06 mV, 337.44 mV and 64.21 mpy, 53.22 mpy, 16.35 mpy respectively.

From the fig. it has been resulted that the soil with highest value of redox potential has very low corrosion rate than the soil with low redox potential. this is because the redox potential is measure of degree of aeration in soil high redox potential indicate high oxygen content while low redox potential value may provide an indication that the condition are conductive to anaerobic microbiological activity which enhances the corrosion rate of steel pipe specimen.

3.6 Soil Chloride, Sulphate and Bicarbonate contents

The collected three different soil samples tested for their salt concentration that is chloride, sulphate and bicarbonate. It is observed that soil 1 is with high salt concentration than other two. Hence corrosion of steel pipe specimen is more severe in soil 1 than other two. Effect of chloride, sulphate and bicarbonate on corrosion of steel pipe specimen as shown in fig. (6-7-8). Also it is resulted that corrosivity of soil sample is in the order of Soil 1> Soil 2> Soil3.

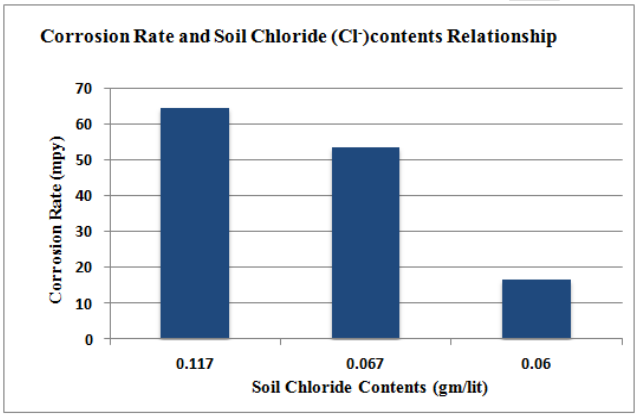

Fig. 6 - Relationship between Corrosion rate and Soil Chloride Content

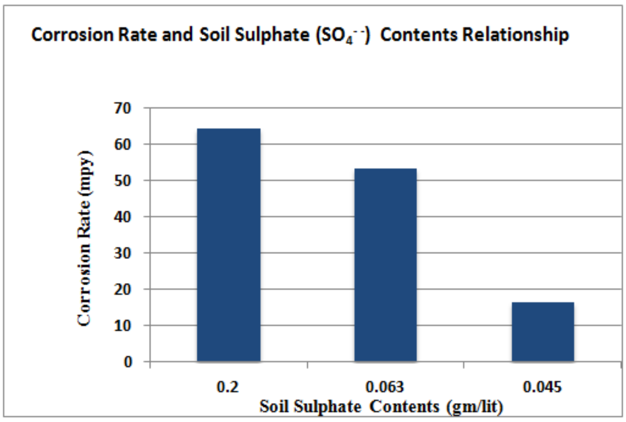

Fig. 7 - Relationship between Corrosion rate and Soil Sulphate Content

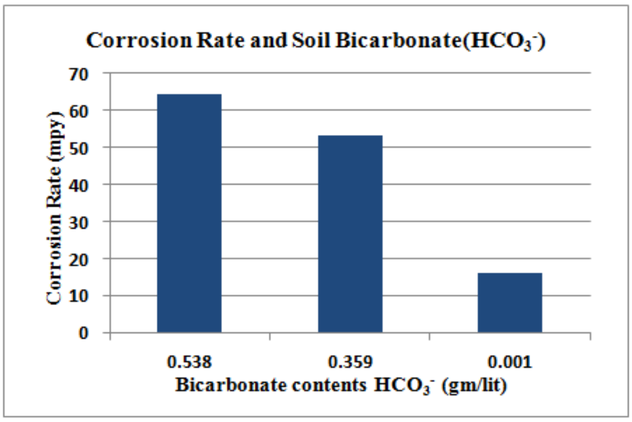

Fig. 8 - Relationship between Corrosion rate and Soil Bicarbonate content

Fig. (6-7-8) shows relationship between soil chloride, sulphate and bicarbonate content and corrosion rate. It has been found that the soil sample 1 has highest value of chloride sulphate and bicarbonate content and high corrosion rate than other two soils. Since the Cl^- , SO_4^{--}, HCO_3^- ions promote breakdown of passive layer of steel and directly participate in anodic dissolution reaction of metal. Hence soil with high chloride, sulphate and bicarbonate content the rate of metal degradation is high.

IV.CONCLUSIONS

The corrosion resistance of steel pipe specimens which were buried in three different soil compositions was studied by potentiodynamic polarization technique. The corrosion resistance of steel pipe in soil medium 3 is more than that of steel pipe in soil 1 and soil 2.

The steel pipe before immersion in soil has corrosion rate 9.15 mpy and after the 7 month of soil exposure corrosion rate of steel pipe in soil 1, soil 2 and soil 3 increased from 9.15 mpy to 64.21 mpy, 53.22 mpy and 16.35 mpy respectively

The corrosivity properties of three different soil samples have been studied. The soil sample 1 has higher conductivity, salt concentration and moisture content than the other two soil samples. The corrosivity of these soils is in the order of Soil 1 > Soil 2 > Soil 3.

Corrosion rate of steel pipe was more in soil having high moisture content, low resistivity, low redox potential, high chloride, sulphate and bicarbonate contents.

REFERENCES

[1]. I.S. Cole, D. Marney, (2012) "The science of pipe corrosion: A review of the literature on the corrosion of ferrous metals in soils", Corrosion Science 56 pp.5–16.
[2]. Nordin Yahaya, (2011) "New technique for studying soil corrosion of underground pipeline", Journal of Applied Science 11(9): pp.1510-1518.
[3]. T. M. Liu,Y. H.Wu, S. X. Luo, C. Sun, 2010 "Effect of soil compositions on the electrochemical corrosion behavior of carbon steel in simulated soil solution", Mat.-wiss. u.Werkstofftech., 41, No. 4.

[4]. Z. Liang. LI Xiao-gang , DU Cui-wei, . 2009 "Effect of Environmental Factors on Electrochemical Behavior of X70 Pipeline Steel in Simulated Soil Solution", JOURNAL OF IRON AND STEEL RESEARCH, INTERNATIONAL, 16(6): pp.52-57.
[5]. A.I.M. Ismail, A.M. El-Shamy, (2009) "Engineering behavior of soil materials on the corrosion of mild steel", Applied Clay Science 42 pp.356–362.
[6]. D. de la Fuente, I. Díaz, J. Simancas, B. Chico, M. Morcillo, (2011) "Long-term atmospheric corrosion of mild steel", Corrosion Science 53 pp. 604–617.
[7]. C.W. Du, X.G. Li, P. Liang, Z.Y. Liu, G.F. Jia, and Y.F. Cheng, 2009 "Effects of Microstructure on Corrosion of X70 Pipe Steel in an Alkaline Soil", Journal of Materials Engineering and Performance Volume 18(2) ,pp.216–220.
[8]. M.N. Norhazilan, Y. Nordin, K.S. Lim, R.O. Siti, A.R.A. Safuan, M.H. Norhamimi, 2012 " Relationship between Soil Properties and Corrosion of Carbon Steel", Journal of Applied Sciences Research, 8(3), pp.1739-1747.
[9]. M. G. Fontana 2005 "Corrosion Engineering" Tata MacGraw Hill Education Private Ltd., New Delhi, Third Edition, pp. 4, 296, 306.
[10]. M. Barbalat, (2012) "Electrochemical study of the corrosion rate of carbon steel in soil: Evolution with time and determination of residual corrosion rates under cathodic protection", Corrosion Science 55 pp.246–253.
[11]. C. Sun, J. Xu, F.H. Wang, C.K. Yu, (2011) "Effect of sulfate reducing bacteria on corrosion of stainless steel 1Cr18Ni9Ti in soils containing chloride ions", Materials Chemistry and Physics 126 pp.330–336.
[12]. X. Wang, J. Xu , C. Sun, (2013) " Effects of Sulfate-Reducing Bacterial on Corrosion of 403 Stainless Steel in Soils Containing Chloride Ions", Int. J. Electrochem. Sci., 8 pp.821 – 830.
[13]. Vanessa de Freitas Cunha Lins, Mitchel Leonard Magalhães Ferreira,Patrícia Alves Saliba, (2012) "Corrosion Resistance of API X52 Carbon Steel in Soil Environment", Journal of Materials Research and Technology 1(3) pp.161-166.
[14]. B. Jegdic, S.Polić-Radovanovic, S. Risti,A. Alil, 2011 "Corrosion Processes, Nature and Composition of Corrosion Products on Iron Artefacts of Weaponry" Scientific Technical Review, ,Vol.61,No.2,pp.50-56
[15]. Z. Liu, Y. Kleiner, (2013) "State of the art review of inspection technologies for condition assessment of water pipes", Measurement 46 pp.1–15
[16]. V.C. Malshe , N.S. Sangaj, (2005) "A simple method for detection of the onset of corrosion of mild steel panel", Progress in Organic Coatings 53 pp.312–314