Electrochemical Corrosion Behavior of Steel Pipe in Alkaline Soil

Vishal M. Bansode, S. T. Vagge, Aniket B. Kolekar

Metallurgy and Material Science, College of Engineering Pune

***Abstract*-This study presents an overview of the corrosion threat to liquid pipelines focusing on the detection of external corrosion. For this steel coupon were buried in three different soil containers for 7 month. Corrosion by soil is a complex phenomenon due to the number of variables involved. In principle, steels should be in the passive state in soils but the presence of water and aggressive chemical species such as chloride ions, sulphates as well as different types of bacteria and stray current can cause localised corrosion. Soils constitute the most complex environment known to metallic corrosion. Corrosion of metals in soil can vary from relatively rapid material loss to negligible effects, depending on soil environment. Soil engineering properties and soil contents are important parameters that influence soil corrosivity and level of corrosion dynamic. The corrosion potential and corrosion rate of buried coupons were studied by EIS technique,**

Keywords: Soil corrosion, Soil properties, Corrosion relationship, EIS, Polarization resistance

I. INTRODUCTION

Underground metal structures are usually expected to have a long working life, Structures such as natural gas, crude oil pipelines and water mains are only some of the many structures reported to have been affected by soil corrosion around the World. Corrosion is the disintegration of metal through an unintentional chemical or electrochemical action, starting at its surface.

The fundamental cause of the deterioration of buried pipeline is soil corrosion. All metals exhibit a tendency to be oxidized, some more easily than others. The corrosion process is usually electrochemical in nature. When metal atoms are exposed to an environment containing water molecules they can give up electrons, become themselves positively charged ions. This effect can be concentrated locally to form a pit, a crack or it can extend across a wide area to produce general deterioration.

Corrosion of buried steel pipe in soil mainly depends on soil properties such as soil resistivity, soil redox potential, soil pH, soil organic content, temperature and chemical composition also by microbial activity. [1] With increase of temperature the driving forces of anodic and cathodic reaction were strengthened in solution. Hence dissolution of sample was aggravated and average corrosion current density was gradually increased. [4]

When pH was strongly acidic, the driving forces for the reaction was fast and corrosion products could not adhere to metal surface resulting increased corrosion of metal. However strongly alkaline soil contains high amount of OH^- ions and which is beneficial for formation of passive film layer on metallic substrate which acts as corrosion protection layer. [4] Corrosion of metals is always associated with development of negative voltage caused by the release of electrons.[16]

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 and chemical composition of three different soils used for study as shown in table 2.

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

Table 2 - 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

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. 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).

2.2 Material preparation

Total 63 pipe specimens were cut from original pipe each having 25.4 mm outer diameter 2 mm thickness and 20 mm length. Out of 63 specimens, 21 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.

2.3 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

2.4 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% NaCl solution. Electrochemical impedance Spectroscopy EIS measurements and Tafel polarization test were performed on steel pipe specimens, which are immersed in three different soil medium, after each month of immersion (0 to 7 months) on Gamry potentiostat instrument (Reference 600). Frequency range was 100 KHz to 10 mHz.

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 Electrochemical Impedance Spectroscopy

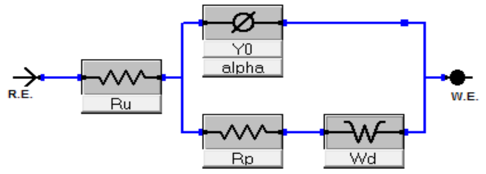

Fig. 1 - Equivalent electrical circuits model used for EIS curve fitting

Fig.(3-8) shows EIS plot of steel pipe specimen in soils of three different composition and corresponding equivalent circuit, where Ru represent the soil electrolyte resistance that is solution resistance, Rp and Yo represent resistance and capacitance of the film and Wd represent Warburg impedance. Fitting results are given in the table (3-4-5).

Table 3 - Nyquist parameters Rp, Ru & Yo for steel pipe specimen immersed in soil medium 1

Immersion time	Rp (ohms)	Y0 (capacitance) Farad	Ru (ohms)	Wd	Zmod (ohms)
0 month	253.0	0.310	5.439	165.86	213.0
1 month	109.3	0.357	29.04	27.32	125.2
2 month	270.1	0.689	3.582	-	128.8
3 month	237.5	0.567	11.80	2.94	138.4
4 month	198.4	1.285	5.860	0.25	77.64
5 month	176.7	0.369	4.924	-	71.79
6 month	31.65	1.757	3.529	1.45	55.45
7 month	34.56	2.145	3.122	-	51.21

Table 4 - Nyquist parameters Rp, Ru & Yo for steel pipe specimen immersed in soil medium 2

Immersion time	Rp (ohms)	Y0 (capacitance) Farad	Ru (ohms)	Wd	Zmod (ohms)
0 month	253.0	0.310	5.439	165.86	213.0
1 month	283.0	0.719	5.655	737.26	210.0
2 month	586	0.115	3.858	2.338	194.3
3 month	601.8	0.187	36.76	2.426	257.8
4 month	380	0176	7.591	1.867	116.5
5 month	245.3	0.915	3.305	70.84	58.63
6 month	184.4	0.797	6.079	2.541	69.12
7 month	110.5	0.410	6.698	3.342	48.79

Table 5 - Nyquist parameters Rp, Ru & Yo for steel pipe specimen immersed in soil medium 3

Immersion time	Rp (ohms)	Y0 (capacitance) Farad	Ru (ohms)	Wd	Zmod (ohms)
0 month	253.0	0.310	5.439	165.86	213.0
1 month	214.0	0.301	21.69	4374.02	390.4
2 month	347.8	0.329	4.245	4.414	431.9
3 month	405.8	0.289	8.678	2.727	419.3
4 month	160.7	0.718	5.793	1.392	338.0
5 month	65.72	1.174	3.430	1.834	110.3
6 month	44.62	0.437	3.381	6.362	111.2
7 month	40.62	1.157	4.088	3.854	110.5

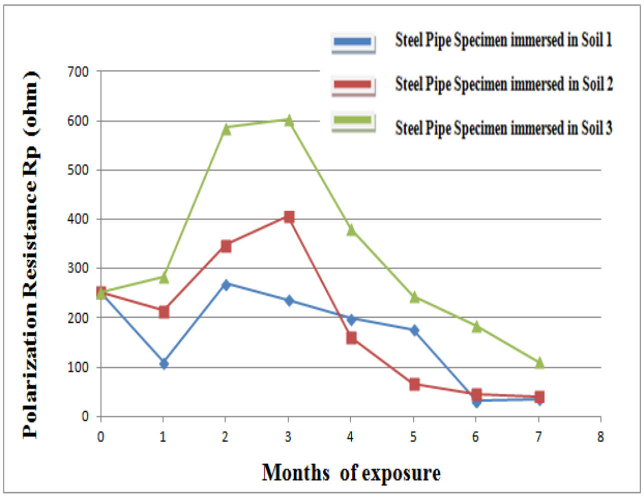

Fig. 2 - Relationship between Polarization Resistance and exposure time

The Nyquist plot shows single time constant semicircle for all steel pipe specimen. From the bode plot it is cleared that initially impedance value of pipe pecimen before immersion is 210.0 Ω. For the steel pipe specimen immersed in soil 1, impedance resistance start decreasing at lower rate upto three month but after three month of immersion steel pipe shows gradual decrease in impedance value. Also for the pipe specimens which are immersed in soil 2, impedance value decreases very slightly upto two month of immersion and then increases upto 257.8 Ω after three month and after subsequent month of exposure impedance value start reducing. For the steel pipe specimen immersed in soil 3, initially impedance value increases upto four month of soil exposure and after the subsequent month of soil exposure the impedance value start reducing gradually.

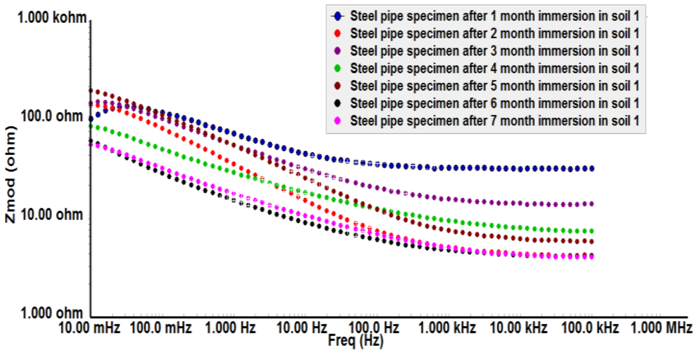

Fig. 3 – Bode curve for the steel pipe specimen immersed in soil 1 for different exposure time

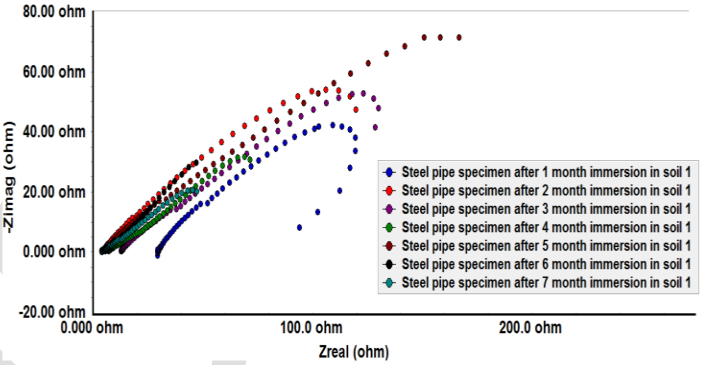

Fig. 4 – Nyquist curve for the steel pipe specimen immersed in soil 1 for different exposure time

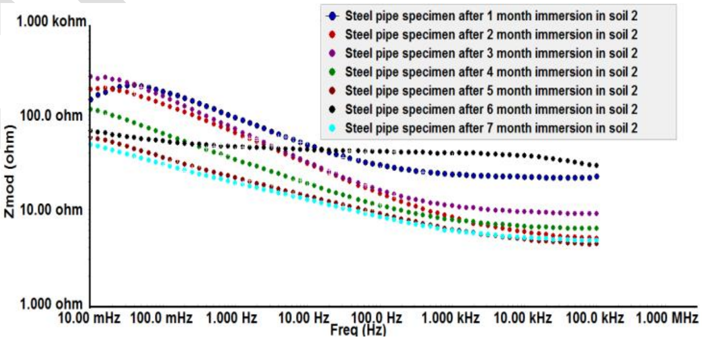

Fig. 5 – Bode curve for the steel pipe specimen immersed in soil 2 for different exposure time

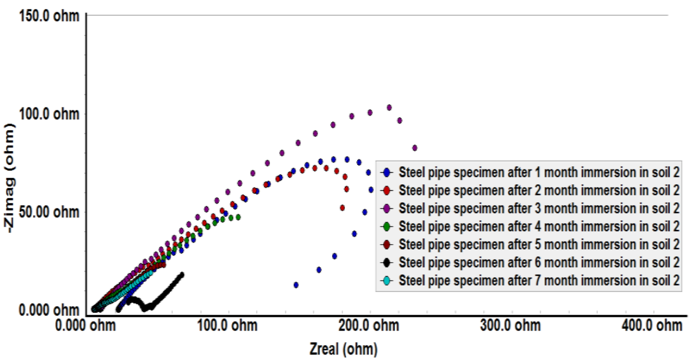

Fig. 6 – Nyquist curve for the steel pipe specimen immersed in soil 2 for different exposure time

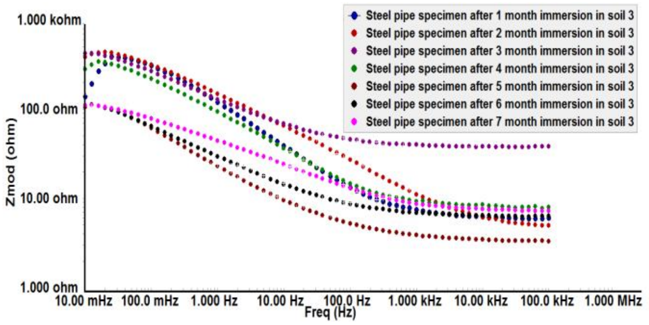

Fig. 7– Bode curve for the steel pipe specimen immersed in soil 3 for different exposure time

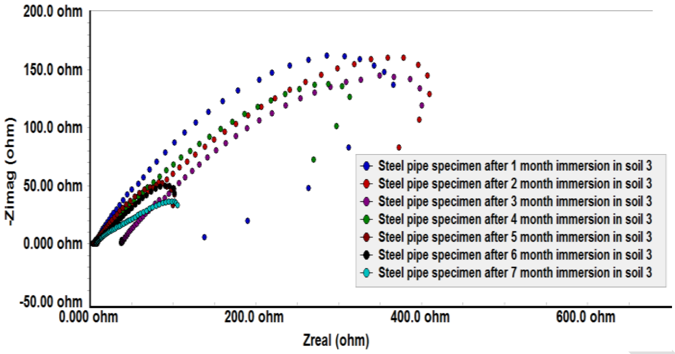

Fig. 8 – Nyquist curve for the steel pipe specimen immersed in soil 1 for different exposure time

Fig.2 shows change in polarization resistance with respect to immersion time for the pipe specimen immersed in three different soils. Comparatively polarization resistance value is highest for pipe specimen immersed in soil 3 and lowest for pipe specimen immersed in soil 1. From the fig. it has been observed that for all steel pipe specimens polarization resistance increased upto 2 to 3 month of soil exposure due to passivation by corrosion products then decreases with immersion time.

IV. CONCLUSIONS

The corrosion resistance of steel pipe specimens which were buried in three different soil compositions was studied by Electrochemical Impedance Spectroscopy . The corrosion resistance of steel pipe in soil medium 3 is more than that of steel pipe in soil 1 and soil 2. Corrosivity properties of soils in in the order of soil 1> soil 2> soil 3

Hence it can be concluded that the metal degradation rate of steel pipe is high in more corrosive soil.

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 "Corrosion Engineering" Tata MacGraw Hill Education Private Ltd., New Delhi, Third Edition 2005, pp. 4, 296, 306.
[10]. M. Barbalat, "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 (2012) 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–