

## Evaluation of Corrosion Behaviour of Pipeline Steel Structure in Onshore Environment

Amadi, S.A & Ukpaka, C.P\*

Department of Chemical/Petrochemical Engineering Rivers State University of Science and Technology Nkpolu P.M.B. 5080, Port Harcourt, Nigeria.  
*Chukwuemeka24@Yahoo.Com\**

---

**Abstract:** *Gas transmission pipelines are susceptible to both internal (gas side) and external (soil side) corrosion attack. Internal corrosion is caused by the presence of salt laden moisture. (O, H and perhaps O in the natural gas). Internal corrosion usually manifests itself as general corrosion. However the presence of chlorides in entrained water also can lead to pitting corrosion damage. The immersion technique can differentiate general from localized corrosion and provide estimate for corrosion rates without external perturbation and the corroding system. In this project, this involves the immersion of carbon steel in these expose location. The specimens are fixed at three different locations. The exposure time vary between 30, 60, 90, 120, 150 and 180 days. From this study the corrosion behaviour of carbon steel have been evaluated based on exposure location.*

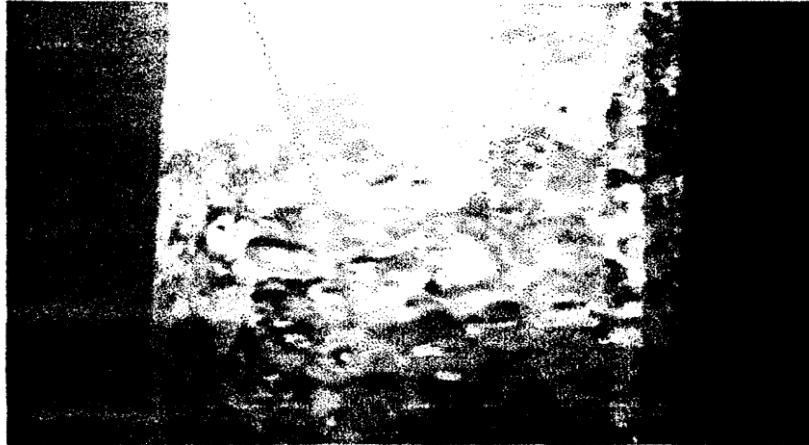
**Keywords:** *Evaluation, Corrosion, Pipeline, Steel, onshore, environment*

---

### 1. INTRODUCTION

Corrosion is one of the most misunderstood and mischaracterized forms of material degradation. Consequently, corrosion analysis and mitigation methods tend to be some of the most misapplied. As recently as 1995, a major study concluded that the cost impact of corrosion to the U.S. economy totaled nearly \$300 billion annually. This represents nearly 4% of the Gross Domestic Product, and is a conservative estimate at best indirect costs, which are substantial and mostly unreported, would greatly inflate the total estimated cost, (Burstein, 2000; Baroux, 1995; Beck and Alkire, 1979; Coates, 2005; Davison and Arnvig, 1993; Dilip et al., 2003; Dunn et al., 2000; Ezuber and Newman, 2005; Frankel and Mcgreedy, 20002). Estimates suggest that about two-thirds of present corrosion-related costs are unavoidable. In addition, corrosion affects our Nation's force effectiveness and readiness levels through the diminished safety and reliability of structures, and electronics, (Hadzima 2008; Hisamatsu and Matsumura, 1999; Job References, 2001; Laycock et al., 2007; Jamie, 2008; Ginzl and Ginzl, 1995; Hoppenbrouwers, 2000; Kuruvilla, 1999; Marcel, 2003; Mattson, 1996). In many cases, corrosion is the life-limiting factor of a component. Corrosive failures can occur unexpectedly at the worst possible moment. Corrosion testing can consume enormous blocks of time, particularly in the case of onshore pipeline. Unfortunately, the timescales involved in such tests preclude the opportunity for proper materials selection. In typical circumstances, new systems may be halfway through their lifecycle before real data on the fielded system would indicate any Corrosion problems. Under the right conditions, accelerated testing may yield data beneficial in selecting the most corrosion resistant materials for an application. Accelerated testing isn't limited to the design stage of a system's lifecycle, but can be used to provide in-field support, as the emergence of sudden corrosion problems on onshore pipeline systems requires quick answers, (Taylor 1991, Moshier, 2005; National Energy Board Report, 1996; Peking, 2006; Rober et al., 2004; Dedriks, 2006; Strehblow, 1995; Wong and Alkire, 1990; Wilde, 2000; Wood et al., 1974). Corrosion consists of an oxidation reaction and a reduction reaction at the surface of the corroding material. The oxidation reduction generates metal ions and electrons; the electrons are then consumed in the reduction reaction, Williams (1990). For environments with water present including moisture in the air, the electrons are consumed by converting oxygen and water to hydroxide ions. In iron and many iron alloys, these hydroxide ions in-turn combine with iron ions to form a hydrated oxide ( $\text{Fe}(\text{OH})_2$ ). Subsequent reactions form a mix of magnetite ( $\text{Fe}_3\text{O}_4$ ) and hematite ( $\text{Fe}_2\text{O}_3$ ). This red-brown mixture of iron oxides is rust, Moshier (2005). The higher the ionic conductivity, the quicker this reaction takes place. This is why water containing electrolytes, such as salt, is far more damaging. Another key point to note is that reducing the amount of dissolved oxygen in solution directly can inhibit corrosion. However, many other

reduction reactions can consume the electrons. In onshore environment, the mechanical characteristics of transit petroleum pipelines made up of thermo mechanically processed steels do not essentially change during the life-time of the pipe. However, the pressurized pipelines are subject to the harmful effects both of the surrounding environments, such as the fresh or salt seawater, and of the materials conveyed in them. One of these effects is corrosion as earlier discussed, Frankel (1998). There exist different types of corrosive defects among which localized, such as pitting, and general ones are those which attract the greatest interest among pipeline operators and research institutes all over the world. Predicting the failure pressure of corroded pipelines with pitting corrosion, and particularly the semi-elliptical one, has been the subject of considerable research in the last decades.



**Fig1.** Onshore Pipeline pitting corrosion

Corrosion is an electrochemical process. It is a time dependent mechanism and depends on the local environment within or adjacent to the pipeline. Corrosion usual appears as either general corrosion or localized (pitting) corrosion. There are many different types of corrosion, including galvanic corrosion, microbiologically induced corrosion, anode current (AC) corrosion, differential soils, differential aeration and cracking. Corrosion causes metal loss. It can occur on the internal or external surfaces of the pipe, in the base material, Pitting occurs when an electrolyte begins to allow the transport of ions between an anode and cathode. Only a small amount of metal is corroded and this is usually referred to as localized attack. The anticipation of pitting on structural members is a critical factor in maintaining component integrity and safety in some cases.

**Comparative analysis:** this is to determine the root cause of a defect or problem, the examination and evaluation of the relevant information to select the best course of action from among various alternatives. It is also the process of breaking a complex topic or substance into smaller parts to gain a better understanding of it as compared to other factors

**Corrosion:** The most accepted definition for corrosion is the destruction of trial material due to a chemical reaction of the material with its environment. Generally, this destruction takes place on its surface in the form of material dissolution or redeposition in some other form. Metallic systems are the predominant materials of construction, and as a class, are generally susceptible to corrosion. Consequently, the bulk of corrosion science focuses upon metals and alloys. Corrosion does occur in polymers and ceramics but the mechanisms are quite different from those of metals.

**Pitting corrosion:** Pitting Corrosion is the localized corrosion of a metal surface confined to a point or small area, that takes the form of cavities. Pitting corrosion is one of the most damaging forms of corrosion. Pitting factor is the ratio of the depth of the deepest pit resulting from corrosion divided by the average penetration as calculated from weight loss.

**Pipeline steel** A pipe line or pipe is a tubular section or hollow cylinder, usually but not necessarily of circular cross-section, used mainly to convey substances which can flow – liquids and gases (fluids), slurries, powders, masses of small solids. It can also be used for structural applications; hollow pipe is far stiffer per unit weight than solid members. In common usage the words *pipe* and *tube* are usually interchangeable<sup>5</sup> but in industry and engineering, the terms are uniquely Depending on the applicable standard to which it is manufactured, pipe is generally specified

by a nominal diameter with a constant outside diameter (OD) and a schedule that defines the thickness. Technical requirements and expectations have escalated continuously as both the oil and gas industry and pipe production have become fully internationalized and very competitive.

**Onshore Environment:** the term refers to pipeline products transportation system based in a place close the shore which on the land, coming from the sea toward the land an inshore breeze, an onshore gale or sheltered from seaward winds, on the edge of the land, an onshore lighthouse. On land, not out in the sea.

The aim of this project work is to comparatively analyze the behavior of pitting behavior of pipeline steel structure in onshore environment, in achieving the following objectives.

Examination of pitting corrosion profiles subsequent to fracture or sectioning in onshore pipeline steel structure. The stages of pitting corrosion on steel. The types/forms of pitting on pipeline steel structure, etc. Concept of pitting corrosion structure on pipeline steel structure in offshore environment (salt water and fresh water). The formation and the effects of pitting corrosion on pipeline steel (alloy steel). Control of corrosion of pipeline steel structure in offshore environment. Etc. Corrosion experiments have not produced entirely satisfactory results. When a commercial useful metal is immersed in water, we know it's going to corrode. The question is, how fast? Since the useful life of most water facilities is often several decades, some corrosion experiments take too long to be practical. If the rate of corrosion is accelerated, the very thing we want to know has been distorted: hence the purpose of this project work is to understand the best practice method to reduced pitting corrosion on pipeline steel structure in onshore environment. While corrosion rates can be studied experimentally, in general these rates change with time Corrosion in fresh water very often results in pitting so that, because of statistical variation in pit geometry, experiments under identical conditions will not yield identical results. The result of changes in experimental conditions may appear to be contradictory. For example, normally an increase in temperature will increase the corrosion rate, but it is possible for an increase in temperature to increase the Lagelier Index to a point where the corrosion rate is greatly reduced. Because of these inherent difficulties, the results of experiments have failed to yield enough information to enable corrosion engineers to calculate the useful life of onshore pipeline or other metallic facilities exposed to water. Nor is chemical thermodynamics particularly useful, since this subject deals largely with Equilibrium conditions. Hence this project work is based upon observation of corroding structures and the application of elementary chemical theory.

## 2. MATERIAL AND METHOD

Corrosion of metals is an electrochemical process that results in the return of metals to their native state such as oxides and salts. The rate and magnitude of corrosion is a direct function of the environment of interest in the soil. Soil is generally a three phase medium that consists of solid particles, liquids and gases all of which can serve as electrolytes. An electrolyte is any substance containing free ions that behaves as an electrically conductive medium. In soils, for practical purposes, the liquid may be considered as water and the gas as air. Depending on the mineralogical composition of the solid particles in conjunction with the dissolved salts or pollutants in the water phase and oxygen in the air phase, a variety of corrosion environments can develop in nature. For metals in soil and/or water, corrosion is typically a result of the contact of the metal with soluble salts. In general, the most corrosive soils contain relatively large concentrations of soluble salts in the form of sulfates and/or chlorides. There are many other factors that can contribute to corrosion including, but not limited to, the state of stress in the steel, metallurgy of steel, the texture and density of the soil, microbial activity, and stray currents. In this chapter an experiment will be carried out using stainless steel in soil (laboratory test) including accelerators such as sodium, sulphates and chloride to form pitting corrosion.

The experimental procedure for this work was carried out in order to evaluate pitting corrosion behaviour on pipeline steel structure in an onshore environment. it was carried out in two different on shore locations samples Oil Mining Lease (OML) 27 and OML 93 respectively.

To evaluate the effect of corrosion behaviour on pipeline steel structure in an onshore environment.

### 2.1 Preparation of Corrosion Coupon

6 pieces of collected stainless steel (coupon) each having a length of 55mm, width 46mm and thickness 0.2mm were washed with distilled water, alcohol and dried using dryer for 12 minutes, and artificial pit was created on the stainless steel using nail and hammer on seven point of each steel

Tests were carried out of the collected onshore samples obtained from OML 27 and OML 93 respectively in Obagi.

## 2.2 Apparatus

Electric (digital) weighing balance, micrometer screw gauge, Hacksaw, tape, plastic containers, Hammer, Nail, Beaker, conical flask and iron brush.

## 2.3 Material

Stainless steel was gotten from steel mill at trans – Amadi for proper study. Onshore samples obtained from location OML 27 and OML 93 owned by Total Fina Elf Nigeria Limited at Obagi.

## 2.4 Procedure

Procedure: Six (6) of the stainless (coupons) were buried at a depth of 2 feet (ft) in a transparent plastic containers. The samples were exposed to natural conditions with weight of each sample previously collected. These coupons were allowed for a period of 180 days (six month) and monitored at every. 30 days (1 month).

## 2.5 Cleaning procedure

There are several ways of cleaning the specimen after removal from the exposed location. One common cleaning procedure consists of holding the specimen under a stream of tap water and vigorously scrubbing the surface of the carbon steel with rubber stopper.

The rubber stopper cleaning methods has been found satisfactory for most corrosion test in practical application involving aqueous solution and also form any other test.

Cleaning method may be classified as: Mechanical, such as scraping, brushing, scrubbing with abrasive, sand blasting and rubber stopper. Chemical, such as the use of chemicals and solvent Electrolytic which involve making the specimen the cathode under an impressed current in a variety of chemical reagent with or without inhibitor added.

The method used here in cleaning the specimen is mechanical method, the specimen was removed from the exposed location and washed with distilled water to remove sand and other impurities. An iron brush was used to scrub the oxide film formed on the carbon steel and while using the brush care was taken to ensure no further loss of metal apart from the film brined on the carbon steel.

After the removal of the specimen from the exposed locations and cleaning process is carried out, the specimen is dried and weighed on an analytical balance. The weight loss of each exposed time is recorded, the recorded weight loss was used in calculating the corrosion rate.

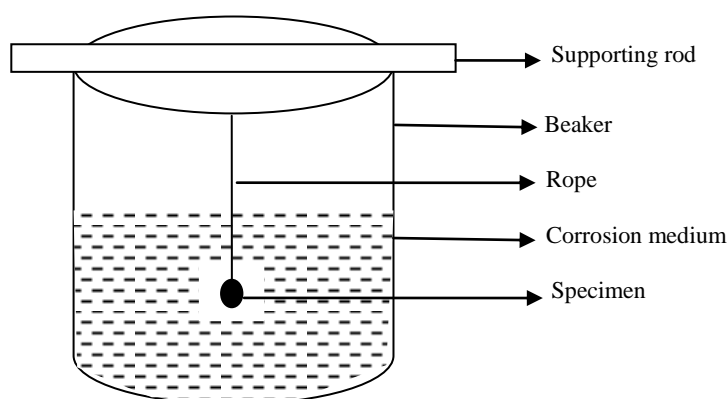


Fig2. Beaker used as corrosion medium

## 2.6 Determination of Loss in Weight

(Corrosion rate) of stainless steel due to the presence of pitting corrosion behaviour on the environment. To determine the loss in weight of stainless steel due to the presence of acidic substances in the environment or medium used which can be used to study the pitting corrosion behaviour on the stainless steel (coupon).

## 2.7 Apparatus

Electric weighing balance, distilled water or Alcohol.

## 2.8 Procedure

After every 30 days (1 month) the metals which the initial masses are known are retrieved from the container, rinsed with distilled water and dried. After drying, the weight is taken by the use of Electronic digital weighing balance.

The weight is subtracted from the initial weight. This process is repeated after every 30 days up to 180 days.

## 3. RESULTS AND DISCUSSIONS

The results of the weight loss and the rate of corrosion of stainless steel as a result of the pitting corrosion effect or behaviour in the environment(s)/media are presented in tables 4.1 and 4.2 respectively.

The rate of corrosion is related to the weight loss as

$$C_R = \frac{\Delta M \times 3.45 \times 10^6}{A \delta t} \text{ (cm/day)}$$

Where  $\Delta m$  = change in mass (mg)  
 $A$  = Area of coupon (sq.m)  
 $\delta$  = Density of coupon ( $\text{g/cm}^3$ )  
 $T$  = time or interval of corrosion (day)

Using the equation 4.1

$$C_R = \frac{\Delta M \times 3.45 \times 10^6}{A \delta t} \text{ (cm/day)}$$

Density of steel =  $7.8 \text{ cm}^3$

Area of the coupon is given by  $2(LW + LW + WH)$

$$A = 2(5.50 \times 4.60 + 5.50 \times 0.02 + 4.60 \times 0.02) = 51.004 \text{ cm}^2$$

CORROSION RATE AFTER 30 DAYS

$$\Delta M = 1.0 \times 10^{-4} \text{ g}$$

$$C_R = \frac{1.0 \times 10^{-4} \text{ g} \times 3.45 \times 10^6}{51.004 \text{ cm}^2 \times 7.8 \text{ g cm}^{-3} \times 30 \text{ days}} = 0.0289 \text{ cm/day}$$

CORROSION RATE AFTER 60 DAYS

$$\Delta M = 8.0 \times 10^{-4} \text{ g}$$

$$C_R = \frac{1.0 \times 10^{-4} \text{ g} \times 3.45 \times 10^6}{51.004 \text{ cm}^2 \times 7.8 \text{ g cm}^{-3} \times 60 \text{ days}} = 0.01156 \text{ cm/day}$$

CORROSION RATE AFTER 90 DAYS

$$\Delta M = 2.0 \times 10^{-3} \text{ g}$$

$$C_R = \frac{1.0 \times 10^{-3} \text{ g} \times 3.45 \times 10^6}{51.004 \text{ cm}^2 \times 7.8 \text{ g cm}^{-3} \times 90 \text{ days}} = 0.1927 \text{ cm/day}$$

CORROSION RATE AFTER 120 DAYS

$$\Delta M = 4.0 \times 10^{-3} \text{ g} \quad C_R = \frac{4.0 \times 10^{-3} \text{ g} \times 3.45 \times 10^6}{51.004 \text{ cm}^2 \times 7.8 \text{ g cm}^{-3} \times 120 \text{ days}} = 0.2891 \text{ cm/day}$$

CORROSION RATE AFTER 150 DAYS

$$\Delta M = 1.9 \times 10^{-2} \text{g}$$

$$C_R = \frac{1.9 \times 10^{-2} \text{g} \times 3.45 \times 10^6}{51.004 \text{cm}^2 \times 7.8 \text{gcm}^{-3} \times 150 \text{days}} = 1.0985 \text{cm/day}$$

CORROSION RATE AFTER 180 DAYS

$$\Delta M = 2.32 \times 10^{-2} \text{g}$$

$$C_R = \frac{2.32 \times 10^{-2} \text{g} \times 3.45 \times 10^6}{51.004 \text{cm}^2 \times 7.8 \text{gcm}^{-3} \times 180 \text{days}} = M = 8.0 \times 10^{-4} \text{g}$$

$$C_R = \frac{1.0 \times 10^{-4} \text{g} \times 3.45 \times 10^6}{51.004 \text{cm}^2 \times 7.8 \text{gcm}^{-3} \times 60 \text{days}} = 1.1177 \text{cm/day}$$

CALCULATION OF THE CORROSION RATE OF STEEL IN OML 93 ONSHORE LOCATION

Using the same equation 4.1

$$C_R = \frac{\Delta M \times 3.45 \times 10^6}{A \delta t} \text{ (cm/day)}$$

Density of steel = 7.8cm<sup>3</sup>

Area of the coupon is given by 2 (LW + LW + WH)

$$A = 2(5.50 \times 4.60 + 5.50 \times 0.02 + 4.60 \times 0.02) = 51.004 \text{cm}^2$$

CORROSION RATE AFTER 30 DAYS

$$\Delta M = 1.0 \times 10^{-4} \text{g}$$

$$C_R = \frac{1.0 \times 10^{-4} \text{g} \times 3.45 \times 10^6}{51.004 \text{cm}^2 \times 7.8 \text{gcm}^{-3} \times 30 \text{days}} = 0.0289 \text{cm/day}$$

CORROSION RATE AFTER 60 DAYS

$$\Delta M = 7.6 \times 10^{-4} \text{g}$$

$$C_R = \frac{7.6 \times 10^{-4} \text{g} \times 3.45 \times 10^6}{51.004 \text{cm}^2 \times 7.8 \text{gcm}^{-3} \times 60 \text{days}} = 0.1098 \text{cm/day}$$

CORROSION RATE AFTER 90 DAYS

$$\Delta M = 1.5 \times 10^{-3} \text{g}$$

$$C_R = \frac{1.5 \times 10^{-3} \text{g} \times 3.45 \times 10^6}{51.004 \text{cm}^2 \times 7.8 \text{gcm}^{-3} \times 90 \text{days}} = 0.1445 \text{cm/day}$$

CORROSION RATE AFTER 120 DAYS

$$\Delta M = 3.8 \times 10^{-3} \text{g}$$

$$C_R = \frac{3.8 \times 10^{-3} \text{g} \times 3.45 \times 10^6}{51.004 \text{cm}^2 \times 7.8 \text{gcm}^{-3} \times 120 \text{days}} = 0.2746 \text{cm/day}$$

CORROSION RATE AFTER 150 DAYS

$$\Delta M = 1.6 \times 10^{-2} \text{g}$$

$$C_R = \frac{1.6 \times 10^{-2} \text{ g} \times 3.45 \times 10^6}{51.004 \text{ cm}^2 \times 7.8 \text{ g cm}^{-3} \times 150 \text{ days}} = 1.9250 \text{ cm/day}$$

CORROSION RATE AFTER 180 DAYS

$$\Delta M = 2.32 \times 10^{-2} \text{ g}$$

$$C_R = \frac{2.23 \times 10^{-4} \text{ g} \times 3.45 \times 10^6}{51.004 \text{ cm}^2 \times 7.8 \text{ g cm}^{-3} \times 60 \text{ days}} = 1.0744 \text{ cm/day}$$

**Table1 .Corrosion Rate of Steel in OML 27 Onshore Location**

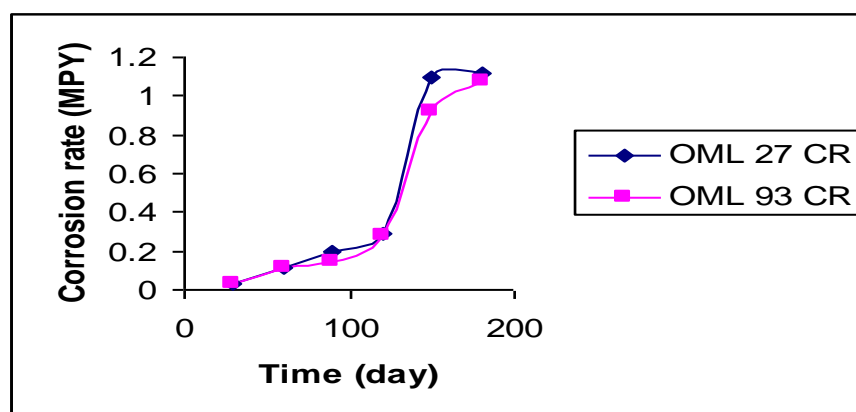
Sample	Period of exposure (days)	Length (cm)	Width (cm)	Thickness (cm)	Initial weight (g)	Final weight (g)	Weight loss (g)	OML 27 C <sub>R</sub>
1.	30	5.50	4.60	0.02	5.253	5.2529	0.00010	0.0289
2.	60	5.50	4.60	0.02	5.256	5.2552	0.00080	0.1156
3.	90	5.50	4.60	0.02	5.253	5.2510	0.00200	0.1927
4.	130	5.50	4.60	0.02	5.253	5.2340	0.00400	0.2891
5.	150	5.50	4.60	0.02	5.253	5.2340	0.01900	1.0985
6.	180	5.50	4.60	0.02	5.253	5.4388	0.0232	1.1177

**Table2. Corrosion Rate of Steel in OML 93 Onshore Location**

Sample	Period of exposure (days)	Length (cm)	Width (cm)	Thickness (cm)	Initial weight (g)	Final weight (g)	Weight loss (g)	OML 93 C <sub>R</sub>
1.	30	5.50	4.60	0.02	5.253	5.2529	0.00010	0.0289
2.	60	5.50	4.60	0.02	5.256	5.25224	0.00076	0.1098
3.	90	5.50	4.60	0.02	5.253	5.2525	0.0015	0.1445
4.	130	5.50	4.60	0.02	5.253	5.2482	0.0038	0.2746
5.	150	5.50	4.60	0.02	5.253	5.2370	0.0160	0.9250
6.	180	5.50	4.60	0.02	5.253	5.2297	0.0223	1.0744

**Table3. Showing the Rate of Corrosion OF OML 27 and OML 93**

Period of Exposure	OML 27 CR	OML 93 CR
30	0.0289	0.0289
60	0.1156	0.1098
90	0.1927	0.1445
120	0.2891	0.2746
150	1.0985	0.9250
180	1.1177	1.0744



**Fig3. Corrosion rate against exposure time for OML 27**

Table 1 through 3 shows the evaluation of pitting corrosion behaviour on pipeline steel in onshore environment. The results show that the stainless steel in OML 27 has the most corrosion rate while the carbon steel in OML 93 shows the least. Thus, its tendency for the occurrence of pitting is on the high side.

Fig.1 and Fig.2 shows the relationship between the corrosion rate (MPY) and the exposure time (day) for both the OL 27 and OML 93 respectively. The plots indicate a decrease in the corrosion rate (CR) as against an increase in the exposure time (days). These results as the exposure time increases the stainless steel that is immersed in the exposure site get reduced because it has been acted upon by corrosion agent and other factors which are basically environmental (humidity, climate change etc). Thus as the day increases the stainless steel will corrode more thereby resulting in the occurrence of localized corrosion.

#### 4. CONCLUSION

An experiment on the evaluation of corrosion behaviour of pipeline steel structure in an onshore environment has been successfully carried out using the weight loss coupon technique, from the result obtained the following conclusion was made. Corrosion rate of stainless steel increases with time. The experiment shows that stainless steel immersed in the sample material (soil) for OML 27 has the highest rate of corrosion than sample material for OML 93 at room temperature and thus it is more susceptible to the attack of localized corrosion. The corrosion rate of stainless steel was very low in OML 93 at room temperature of 25°C. With increase in temperature, (25°C - 35°C) the corrosion rates increase. From the corrosion rate - exposure time (days) graph, it is possible to calculate an average corrosion rate for a particular exposure time and thereby obtain the corresponding corrosion extent.

#### REFERENCES

- [1] Baroux, B. Further Insights on the Pitting Corrosion of Stainless Steels, Corrosion Mechanisms in Theory and Practice, P. Marcus and J. Oudar, Ed., Marcel Dekker, 1995, p 265.
- [2] Beck, T.R. and Alkidre, R.C Electrochem. Soc., Vol 126, 1979, p 1662.
- [3] Burstein G.T., and Mattm, S.F. The Nucleation and Early Stages of Growth of Corrosion Pits, Critical Factors in Localized Corrosion II, Vol PV95- 1 5, P.M. Natishan, R.J.
- [4] Burstein G.T., (Influence of treatment and working conditions on pitting corrosion resistance of stainless steels), PhD thesis, VDS Zilina, (2000).
- [5] Coates, T,F Mialowska: Pitting and crevice corrosion. NACE International, Houston, Texas, 2005.
- [6] Davison, R.M. and Arnvig, P.E. Paper 209, Proc. 12<sup>th</sup> International Corrosion Congress, (Houston, TX), 1993, p 1477.
- [7] Dilip Tailor, Wayne Hodgins, Nick Gritis "Field joint developments and compatibility considerations", BHR 15<sup>th</sup> International Conference on Pipeline Protection, 2003.
- [8] Dunn, D.S. Pan, . Y.-M. and Cragnolino, G.A. "Stress Corrosion Cracking, Passive and Localized Corrosion of Alloy 22 High Level Radioactive Waste Containers," Report Paper 00206, Corrosion 2000, NACE, 2000.
- [9] Ezuber H. and Newman, R.C, Growth-Rate Distribution of Metastable Pits, Critical Factors in Localized Corrosion, 2005 Vol PV 929,
- [10] Frankel G.S. and McCreery, R.L. Interface, "Alternatives to Chromium for Metal Finishing," Report 0273RE95, National Center for Manufacturing Sciences, Vol 34, 2002
- [11] Hisamatsu, T. Yoshii, and V. Matsumura, Electrochemical and Microscopical Study of Pitting Corrosion of Austenitic Stainless Steel, Localized Corrosion, 1999 Vol NACE-3,
- [12] Jamie Cox (2008). Three Layer High Density Polyethylene Exterior Pipeline Coatings:
- [13] Job References And Case Histories", BHR's 14<sup>th</sup> International Conference on Pipeline Protection, 2001.
- [14] Laycock, N.J Moayed, M.H. and Newman, R.C. (2007). Prediction of Pitting Potentials and Critical Pitting Temperatures, Critical Factors in Localized Corrosion II, Vol PV 95-15, P.M.
- [15] Ginzei, E.A., and Ginzel, R.K., Study of Acoustic Velocity Variations in Line Pipe Steel. Materials Evaluation May 1995, Volume 53 Number 5.
- [16] Hadzima, T. D . "Electrochemical Methods of Corrosion Testing," Metals Handbook, Vol. 13, ASM, 1987, PP. 212-228
- [17] Hoppenbrouwers, M.B., 2000, MSc Röntgen Technische Dienst By, Rotterdam. Advanced Ultrasonic Methods For In Service Condition Assessment of Industrial Process Installations. NDT.net, March 2000, Vol. 5, No. 03.



- [18] Kuruvilla, A.K., Life Prediction and Performance Assurance of Structural Materials in Corrosive Environments - A State of the Art Report (AMPT-15), AMPTIAC, 1999.
- [19] Marcel Roche "How Total manage pipeline corrosion control", BHR 15<sup>th</sup> International Conference on Pipeline Protection, 2003
- [20] Mattson, E., 1996k Basic Corrosion Technology for Scientists and Engineers, Second Edition, Bourne Press, Bournemouth, United Kingdom.
- [21] Moshier A.K., Life Prediction and Performance Assurance of Structural Materials in Corrosive Environments - A State of the Art Report (AMPT-15), AMPTIAC, (2005).
- [22] National Energy Board Report of the Inquiry. Stress Corrosion Cracking on Canadian Oil and Gas Pipelines. November 1996.
- [23] Peking (Pitting corrosion of AISI 31 6Ti steel at various operating conditions). PhD Thesis, U v Dine, jIma 2006 (in Slovak)
- [24] Robert Worthingham, Malt Cetiner, Meera Kothari, Trans Canada PipeLines Ltd., Calgary, Alberta - "Two coating systems pass tests for arctic use", Oil & Gas Journal November 15, 2004
- [25] Sedriks, A.J., Effects of Alloy Composition and Microstructure on the Localized Corrosion of Stainless Steels, Advances in Localized Corrosion, 2006 Vol NACE-9, H. Isaacs,
- [26] Strehblow, H.H. Mechanisms of Pitting Corrosion, Corrosions Mechanisms in Theory and Practice, P. Marcus and I. Oudar, Ed., Marcel Dekker, 1995, p.201.
- [27] Taylor "Corrosion Tests and Standards: Application and Interpretation," ASTM, (1991).
- [28] Wong K.P. and Alkire, R.C. J. Electrochem. "Conducting Cyclic Potentiodynamic Polarization Measurements for Localized Corrosion Susceptibility of front, Nickel-, or Cobalt-Based Alloys," G 6h86, Annual Book of ASTM Standards ASTM Soc., Vol 137, 1990, p 3010
- [29] Wilde, B.E. (2000). On Pitting and Protection Potentials: Their Use and Possible Misuses for Predicting Localized Corrosion Resistance of Stainless Alloys in Halide Media, Localized Corrosion, Vol NACE-3, R.W.Staehle, Y.
- [30] Wood, G.C. Sutton, W.H. Richardson, J.A. Riley, T.N.K, and Malherbe, A.G. The Mechanism of Pitting of Aluminium and Its Alloys, Localized Corrosion, R.W. Staehle, B, P. Brown, J. Kruger, and A. Agrawal, Ed., NACE, 1974, p 526.