

*Full Length Research Paper*

# Comparative analyses of corrosion rates of subsurface storage tanks (metals) with some mechanical properties

Ezi, C. W. I., Owate, I.O.\* and Abumere, O. E.

Department of Physics, University of Port Harcourt, Choba, Rivers State, Nigeria.

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**A comparative study of the corrosion phenomena of subsurface storage tank vessel in different media has been performed. The corrosion rates of the system was determined and compared with some mechanical properties of the tank materials. The corrosion rates were calculated from the data obtained by weight loss technique. The tensile and impact strengths and hardness of materials were obtained by standard methods. It was observed that increasing corrosion rates led to gradual reduction of mechanical properties. For example, there were reduction in tensile strengths, hardness and yield strengths. Also acidic medium had greater impact on the tanks than the basic and natural media. Consequently by proper control procedures, it has been possible to reduce the effect of corrosion upon subsurface tanks.**

**Key words:** Corrosion, acid, base, tanks, degradation.

## INTRODUCTION

Petroleum storage vessels are usually made from iron and steel reinforcement structures. In some cases the materials consist of alloys of metals and this makes the system very much prone to corrosion attacks with resultant failures (Craig, 1989; Omodafe and Ovri, 2004). The consequence of these unplanned disruptions to service stations, marketers and consumers is usually enormous and costly. Some of the immediate resultant effects include process operation stoppages, loss of valuable products, and introduction of hazardous environment, destruction of property and in most cases loss of lives (Okoroafor, 1999; Owate et al., 2002). The occurrence of the above scenario could be reduced if important stakeholders such as petroleum consumers relate to each other with the understanding of the importance of health and safety as they relate to profit margin. In some cases, the marketers (filling stations) cut-corners in terms of proper site preparations and installations of facilities with a view to maximising profit. This unethical practice is unacceptable especially when one realises that the filling stations are areas where subsurface storage under-ground tanks are normally installed. It therefore suffices to state that the ethics of sound environmental practices

and sustainable development should be encouraged.

Equally important are the works of monitoring units of statutory institutions, consultants and researchers who from time to time should be able to act in the advisory capacity and in the determination of suitable conditions for such installations and site investigations (Craig, 1989; Owate and Abu, 2003). The seriousness of the problem lies on the fact that most marketers and in fact petroleum filling stations have observed with dismay and frustrated-defeat; the following phenomena (Omodafe and Ovri, 2004).

- I. Leakages from underground surface tanks
- II. Contaminated petroleum products usually mixed with water or solid particulates.
- III. Water thrusting of tanks upwards during wet-seasons within the Niger Delta region of Nigeria.
- IV. Irregular shortage of petroleum product arising from pit-corrosion processes.

There is no doubt that most of the features listed as problems above are in part influenced by corrosion and improper site preparation. These could arise from unsuitable or prevailing environmental factors within the region (Funke, 1983; Tsuru and Nishikata, 2000; Harvey, 2000). It has been stated that the cost of losses from corrosion induced failures per annum if quantified is very great (Zin

\*Corresponding author. E-mail: [owateio@yahoo.com](mailto:owateio@yahoo.com)

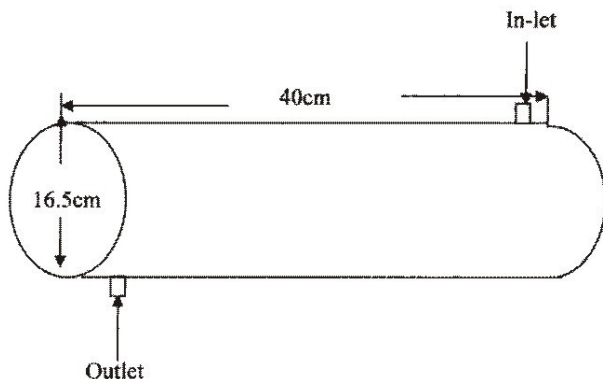


**Figure 1.** A typical petrol storage tanks from Uniport filing station. (Installed In 1977 and Failed in 1996).

et al., 2000; NACE Standards, 1970). Consequently, the significant impact of such losses on the national economy, health and safety are however not fully quantifiable (Tsuru and Nishikata, 2000; Alexander and Duc 1998).

In contrast, it was observed that iron pipes buried in bone dry soil do not easily degrade by corrosion process. (However, due to the diverse soil composition and the natural environmental conditions; corrosion of underground storage tanks is inevitable (Harvey, 2000; Omodafe and Ovri, 2004). Natural processes such as rain (acid or alkaline), springs and rivers, global warming and increasing changes in climate add to corrosion rates and processes (Anyahara, 1999; Brauksieck, 1998). Consequently in the Deltaic region of Nigeria where acid rain is a prevailing fact, the problem of corrosion could be drastic.

The present study was motivated by the degree of corrosion and loss of product observed on some subsurface petroleum storage tanks at the University of Port Harcourt, Choba in 1999. The tanks were installed in 1977 but twenty-two years later corrosion of the tanks was so severe that, they were no longer useful (Figure 1). This work will in part address the problem of relationships between corrosion process of metallic system and storage tanks. Environmentally simulated conditions and mechanical properties of some metal products shall be investigated. Thereafter, comparative analysis of corrosion rates and other the parameters will be carried out.



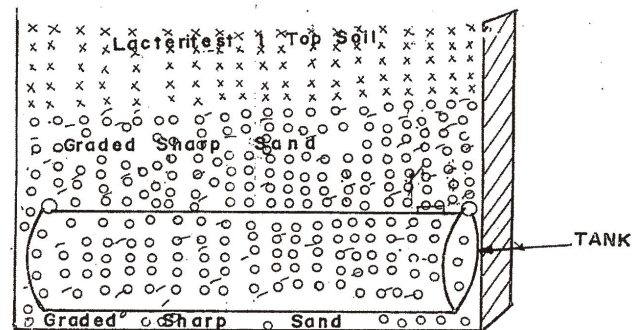
**Figure 2.** Typical prototype underground storage tank.

## MATERIALS AND METHOD

Seven different proto-type petroleum storage tanks (made of iron and steel of 5 mm thickness) were designed and constructed to specifications (Figure 2). Similar design and construction have been used elsewhere and details about the system-design and the corrosion control measures employed have been presented by other workers (Owate et al., 2002; Omodafe and Ovri, 2004).

Standard measures for corrosion protection control were adhered to with a view to reducing corrosion influence on the tanks. Each tank was properly cleaned and polished using sand-paper and washed with water and then dried in air at about 38°C. Thereafter, they were coated with corrosion resistant resin, paint and lightly sand-blasted. Selected tanks (D to G) were shielded with polyethylene cellophane materials to further reduce corrosion impact. Care was taken at this stage to avoid air-bubbles being trapped by making sure the coating room was air-tight, dust free and air particulates were equally reduced.

Trenches were dug accordingly at chosen stations (A, B, C, D, E, F and G) to accommodate the tanks which bore the same identification marks presented above. Soil samples were collected from each station and chemically analysed before and after the experiment. Atomic absorption technique was employed in the analysis of the soil samples. This was conducted in Port Harcourt at NNPC quality control laboratory and the National Metallurgical Research Centre Jos. Each station was specially prepared with graded soil samples as shown in Figure 3.



**Figure 3.** Trenches for tanks.

Part of the floor and walls of the trenches were blinded using a mixture of sharp sand, gravel, chippings, cement and water. This was to enable the tanks to be held-fixed in position during the exposure period. The environment for the control station G was carefully prepared using graded gravels, sharp-sand and topsoil of varying textures. This precautionary measure created a suitable control condition that could reduce corrosion in sample G. Also natural and simulated conditions were later created for samples A to F as shown in Table 1.

Tank G was properly shielded with ethylene cellophane material after due corrosion protection control, and then buried in the station in which the soil samples were graded after the preparation of the trenches each tank was gradually lowered and covered with soil and sand as indicated in Figure 3. The system was buried for an average period of 175 days. Thereafter, they were exhumed and the corrosion rates determined by weight loss technique (Owate et al., 2002; NACE Standards, 1970).

Consequently, each tank was periodically removed and subjected to corrosion tests. In addition, a piece of metal (for mechanics test) sample each was buried along side the tanks test. During the

**Table 1.** A summary of the conditions for which the samples were exposed.

Stations	Samples	Simulated Environment
A	Tank – A	Natural but neutral soil environ
B	Tank – B	Natural soil infested with H <sub>2</sub> SO <sub>4</sub>
C	Tank – C	Natural soil infested with NaOH
D	Tank – D	Tank shielded with cellophane and buried in H <sub>2</sub> SO <sub>4</sub> soil
E	Tank – E	Tank shielded with cellophane and buried in NaOH infested soil
F	Tank – F	Tank shielded with cellophane and buried in natures but neutral soil
G	Tank – G	Buried under well-controlled environ

**Table 2.** pH and chemical composition of soil specimens.

Sample Stations	Concentrations (Wt %)											
	SiO <sub>2</sub>		Al		Fe		Ca		Mg		PH	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
A	99.78	99.67	0.064	0.091	0.004	0.005	0.0003	0.0001	0.0005	0.0006	6.49	6.65
B	99.28	99.86	0.034	0.09	0.005	0.005	0.0006	0.0001	0.0005	0.0005	5.51	5.62
C	99.54	99.70	0.040	0.89	0.005	0.008	0.0016	0.0012	0.0003	0.0002	8.18	8.15
D	99.81	99.73	0.030	0.89	0.31	0.010	0.0053	0.0012	0.0004	0.0002	5.46	5.38
E	99.68	99.66	0.018	0.14	0.014	0.029	0.0052	0.0044	0.0003	0.0004	8.58	8.55
F	99.89	99.48	0.078	0.69	0.081	0.65	0.0001	0.0009	0.0007	0.0005	6.63	6.78
G	99.86	99.89	0.091	0.96	0.016	0.027	0.006	0.0006	0.0008	0.0005	6.85	6.92

**Table 3.** Impact test (Charry Scale – Unnotched Samples).

S/NO	A	B	C	D	E	F	G
1	236	226	308	304	238	216	320
2	230	225	302	301	236	214	318
3	228	223	300	299	232	211	317
4	233	220	298	287	227	207	315
5	221	216	282	276	220	205	314
6	210	210	277	270	217	204	314
7	176	188	254	24	200	184	312
8	170	182	220	224	190	179	310
9	165	180	205	217	186	177	300
10	162	178	202	210	180	173	298
11-	160	165	196	208	177	169	284
12	158	162	192	206	170	162	282
% Decrease	33	28	18	32	15	25	12

process, samples were thoroughly washed, dried, inspected visually, re-weighed and later re-buried within their respective environments after the experiments and tests. For each station, the piece of the tank material that was originally buried alongside was periodically removed for hardness, impact and tensile strength tests. The Rockwell “C” scale method was applied for the hardness test whereas the un-notched chary method was applied for the impact test. Standard test specimens were prepared and the test ends were fixed into groups; one of which was attached to the load measuring device on a universal tensile machine and the other to the straining device. All the specimens were tested in air at room temperature (37°C) using INSTRON universal Tensile machine Model TT- DNL – A0674. Its gauge length was 50 mm at constant displacement rate of 0.01 mm/min. Specimens of 12.5 mm width and thickness of 4 mm were applied and the mean recorded.

## RESULTS AND DISCUSSION

Visual observation revealed patched of unevenly distributed red oxide deposits (Figure 1). These could have been due to corrosion degradation of the tanks. It has been well known that one of the products of corrosion process is the production of the metallic oxides that might have arisen from the electrochemical processes (NACE, 1984). However the significance of the present observation is the spotted-patches of the oxides that were eating deep into the metal surface thereby suggesting corrosion by pitting-mechanism. The entire external surfaces of the tanks were covered with spotted corrosion pattern. Figures 1 and 2 compare favourably as both indicate corrosion pitting pattern, which might have been generated from the harsh Niger Delta acidic oil environment.

The chemical analyses of the soil samples collected from the stations (Table 2) indicated that silica (SiO<sub>2</sub>) was the major component whereas oxides of Aluminium, iron, calcium, and magnesium were identified as impurities. There were no significant changes in the concentrations

of the constituent components before and after the entire experiment. This was because the stations were regularly monitored and their acidic or basic contents of the soil replenished where needed.

Table 2 shows that the pH values were in part maintained through out the study period. Part of this analyses became necessary because of the extensive work on acid-rain within the Niger Delta region where the current investigation was performed (Alexander and Duc, 1998; Harvey, 2000).

Comparatively, the soil samples can be classified as being fairly acidic due to the regular acid-rain experienced in the area during the wet season. Relatively stations B and D were intentionally made more acidic so as to verify the impact of acidic media on the system. As stated earlier, the samples (Tanks) were removed from the soil locations and identified by the letters A, B, C, D, E, F and G (Table 3). They were washed, cleaned, dried, re-weighed and photographed. The corrosion rates were calculated using the formula C.R.

$$(MPY) = \frac{\Delta\omega 534}{A T D} \quad \dots \quad 1$$

Where  $\Delta\omega$  = loss is weight  
A = Surface Area Exposed  
T = Exposure Time (Hrs)  
D = Density of Material

The results obtained for the entire period of five and half years are presented in Figure 4. These results indicate three distinct regions of corrosion activities. They are the high, moderate and low corrosion-influenced degradations periods. The first lies between 1 and 250 days, followed by 251 and 650 days, and 651 and 1,950 days

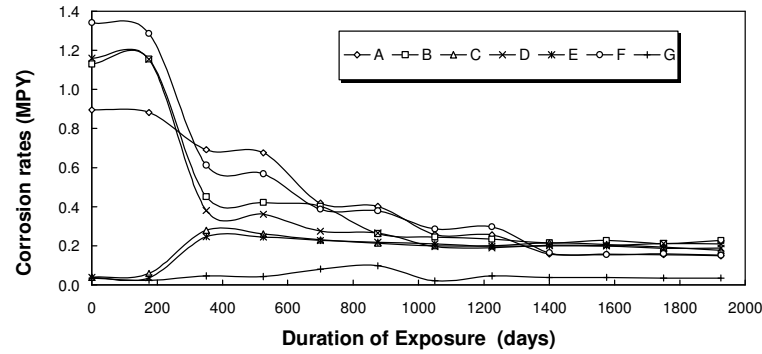


Figure 4. Variation of corrosion rate with time of exposure.

Table 4. Tensile strengths indicating yield strengths and % elongation.

	A			B			C			D			E			F			G		
	YS	TS	Σ	YS	TS	Σ	YS	TS	Σ	YS	TS	Σ	YS	TS	Σ	YS	TS	Σ	YS	TS	Σ
1	44	71.6	21	36.5	66.2	19	46.1	82.2	21	38.4	76.1	23	46	84.1	23	45	76.2	22	48	86.2	19
2	38	71.4	18	30	60.0	20	45	80.9	20	40	75.4	21	45	84.0	20	44	76.0	20	44	86.1	18
3	36	71.5	20	37	64.3	19	46	81.5	21	41	75.4	20	46	83.2	21	45	75.1	21	46	84.4	18
4	42	70.6	21	40	64.1	19	44	80.2	29	40	72.4	18	44	82.4	20	44	70.5	21	45	83.0	19
5	46	71.2	18	41	62.4	20	45	74.6	24	38	61.2	18	42	74.1	20	44	68.4	20	40	76.4	20
6	41	64.4	19	38	52.5	19	46	72.0	24	38	60.1	22	40	68.4	18	38	60.5	18	42	75.4	21
7	43	60.2	20	37	50.2	20	40	69.5	20	35	58.3	20	48	67.2	20	41	58.2	18	45	69.1	21
8	40	57.4	18	36	50.4	20	42	62.8	26	40	56.0	21	46	66.4	20	40	56.0	19	40	68.5	18
9	38	56.2	20	30	50.4	18	41	61.8	21	38	54.4	20	44	66.3	19	38	56.4	20	41	68.0	17
10	39	56.4	21	38	50.5	18	45	62.4	20	40	54.5	18	46	66.4	20	40	55.8	20	42	67.9	20
11	40	55.3	20	40	50.5	20	40	61.9	18	41	54.5	20	41	66.5	21	38	55.2	21	44	68.2	21
12	41	55.6	20	41	50.6	21	41	62.5	18	39	54.6	20	40	66.5	22	38	55.4	21	48	68.1	18

YS = Yield Strengths  
 TS = Tensile Strength  
 Σ = % Elongation

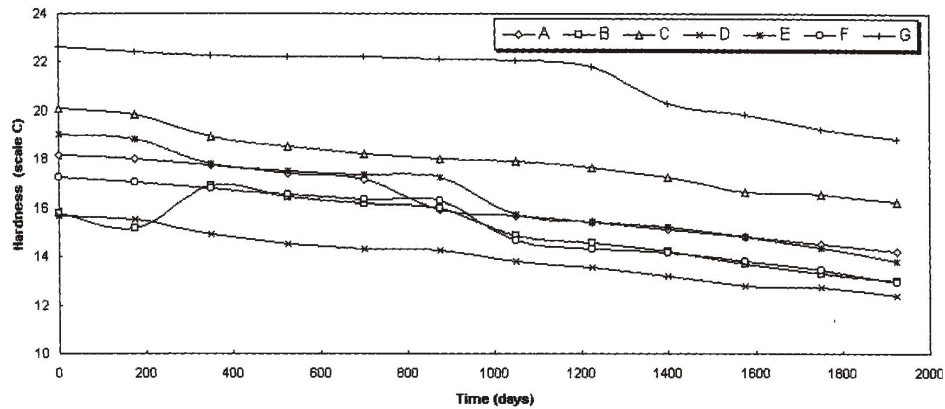


Figure 5. Variation of hardness with time of exposure of tanks.

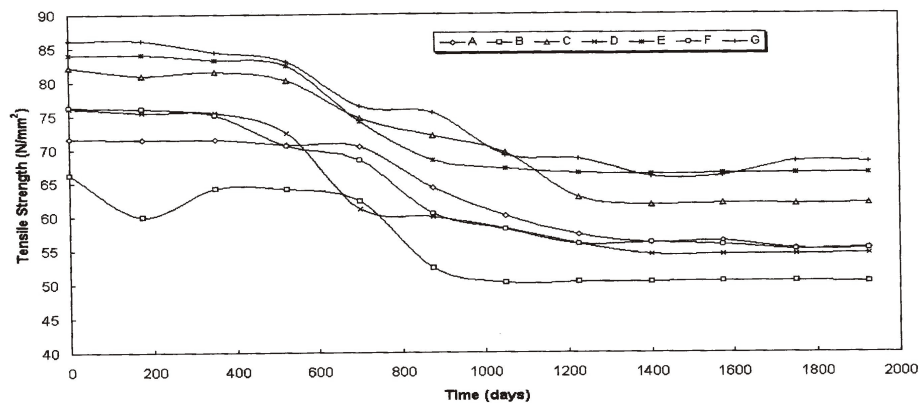


Figure 6. Variation of tensile strength with time of exposure of tanks.

respectively. Thus, apart from samples C, E and G the rest of the specimens indicated exponential decrease in corrosion rates within the high and moderate corrosion periods. For example samples C, E and G, appear to signify periods of inactivity during the first two hundred days thereafter, increases in corrosion rates were observed and lastly a relatively constant corrosion rates were obtained towards the end. Generally, it was noticed that after 650 days most of the specimens maintained constant corrosion rates. These sequences of corrosion events points to the fact that, during the initial and final periods, the corrosion rates was minimal whereas corrosion activities became very pronounced after about two hundred days (200 days). This implies that at the onset, the tanks were hardly attacked by corrosion and later the process of corrosion was gradually initiated. Consequently, due to corrosion protection control measures such as coating and sand blasting, the rate of corrosion decreased, with increasing time period. Towards the later part of the period (after 650 days), the corrosion rates were fairly constant because of the oxide films formed as protective coatings. This could have in part been respon-

sible for the reduction in corrosion. However, it was noticed that material degradation was progressive as some of the corrosion pits were increasing in depth and area. Similar observations have been reported by other researchers (Di-maggio et al., 1998; Okoroafor, 2004). It was equally pointed out that the thin oxide films coating could have been responsible for the increasing depths of the pits, especially if they were in-part broken. Consequently, it is hereby suggested that the major corrosion attack on the metallic tanks occurred within the first 1,200 days. This would have assisted in the degradation of materials (Table 4).

In confirmation, the tensile strengths and hardness tests indicated gradual reduction in the mechanical strengths of the materials (Figure 5 and 6). However, samples C, E and G (under NaOH and control environment) were of relatively higher strengths when compared to the other groups of samples A, B, D, and F. Comparatively, sample G which was exposed to controlled environment had the lowest decrease in tensile strengths, followed by C and then E. It could be recalled that samples C and E were both exposed to NaOH infested soil environment but in

addition specimen E was shielded with ethylene cellophane materials. It became obvious that acidic soil environment increases corrosion processes thereby increasing the corrosion degradation process. Even though the basic soil environment affected corrosion processes, it had minimal impact on the system. In addition, shielding the tank with cellophane material did not significantly influence the corrosion process for sample E.

Tables 3 and 4 are the detail of the impact test results and the tensile strengths of the materials during the period of exposure. The tensile strength data contains the elongation  $\Sigma$  and the yield strengths. There was no significant difference in the percentage elongation  $\Sigma$  but the yield strengths decreased with time, which suggests possible failure in due period of time. Also, the impact energy values decreased with time and sample C recorded the largest amount of impact energy.

### Conclusion

The degradation of metallic tank materials could be divided into three different corrosion activity periods. The first period consists of the initial dormancy period and an experientially decreasing corrosion rate region. This is followed by a moderate corrosion attack region and a fairly constant corrosion phenomenon period that could lead to destructive materials failures. The tensile strengths, hardness and impact strengths of the tank materials compared favourably with the corrosion process. In fact, the parameters obtained suggested that chances of sudden failures if not properly checked are inevitable. This is because, with increasing time of tank exposure to the subsurface soil composition, degradation of the tanks rapidly sets in. Thus, by monitoring the corrosion rates of metallic tank vessels, it could be possible to predict the life span of the subsurface tanks. This will be the subject of part two of work as it suffices to state that corrosion impacts affects the mechanical properties of subsurface tanks.

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