# USE OF *Vernonia amygdalina* (VA) AS A CORROSION INHIBITOR ON SUBSEA TRANSMISSION PIPELINE

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**Abstract:** In this research the *Vernonia amygdalina* (VA) solution was prepared and utilized in slowing down the corrosion of Subsea Transmission Pipelines (STP) in harsh offshore environment. The specimens were kept in a workable state to prevent them from any preferential attack. These specimens were rinsed in distilled water, dried and weighed to obtain the initial weight. 6 Aluminum (Al) and 6 Mild steel (MS) are used as samples and immersed into different containers of seawater and 0% of VA solution as our control experiment. The others were immersed in a 5, 10, 15 and 20% of the VA solution. At various time interval values are obtained and graphs plotted on weight loss and corrosion rate versus time. After about 200 hours it was observed that at different time and percentage of the VA solution have different effects on the specimen. It was also noticed that the VA solution was gradually losing its effectiveness. In view of this, VA has proven as a viable solution for corrosion prevention on STP, if more inhibitors are added regularly to sustain the effectiveness of the anti-corrosive solution.

**Keywords:** *Vernonia amygdalina*, corrosion rate, environment, transmission pipeline, weight loss

**Nomenclature**

| | | |
|---|---|---|
| $A$ | - | *Metal reactant* |
| $A_s$ | - | *Total area of specimen* |
| $Al$ | - | *Aluminum* |
| $B$ | - | *Nonmetal reactant* |
| $B_s$ | - | *Breadth of the specimen* |
| $C$ | - | *Oxidized product* |
| $CR$ | - | *Corrosion rate* |
| $D$ | - | *Reduced product* |
| $D_1$ | - | *Density of mild steel* |
| $D_2$ | - | *Density of Aluminum* |
| $D_s$ | - | *Bore diameter of specimen* |
| $H_s$ | - | *Thickness of the specimen* |
| $K$ | - | *Rate of corrosion constant* |
| $L_s$ | - | *lLength of the specimen* |
| $MS$ | - | *Mild steel* |
| $STP$ | - | *Subsea Transmission Pipelines* |
| $t$ | - | *Time* |
| $T$ | - | *Time of exposure in hours* |
| $VA$ | - | *Vernomia Amygdalina* |
| $WL$ | - | *weight loss* |
| $\Delta W$ | - | *Change in Weight* |

## Introduction

Corrosion is an undesirable deterioration of a material as a result of its interaction with its environment which adversely affects the reserved properties of the material. Corrosion reduces the structural integrity of pipelines, makes it deteriorate and over spill its contents into the environment thereby rendering it an unsafe channel of transmission. Beavers (2007) and Ilman and Kusmono (2010) looked at the generaldefinition of corrosion as the degradation of material through environmental interactions; which includes manmade and naturally occurring structures. Corrosion can be classified as dry and wet corrosion, chemical and electrochemical corrosion.

Several authors in their studies discovered that most corrosion problems encountered fall into five basic categories: uniform or general corrosion looked into by Fontana (1986), localized corrosion by the Encyclopedia of Electrochemical website (2001), metallurgical induced corrosion by Natarajan and Fontana (2006), mechanically assisted corrosion by Fontana and Greene (2010) and stress corrosion cracking by Beavers *et al*. (2007). These five basic types can be broken down into different forms; namely the general or uniform corrosion, galvanic corrosion, crevice corrosion and pitting corrosion. Others are inter-granular corrosion, micro biologically influenced corrosion, erosion corrosion and stress cracking corrosion, especially from the marine environment. Umoh and Nitonye (2015) conducted research in stress cracking corrosion. The environmental interaction of the metal can be represented by Equation 1 as shown below and the example in Equation 2.

$$A + B \rightarrow C + D \quad (1)$$

**Where** A = Metal reactant, B = Nonmetal reactant, C = Oxidized product and D = Reduced product

$$4Fe + 2H_2O + 3O_2 \rightarrow 2Fe_2O_3{\cdot}H_2O \quad (2)$$

***Corrosion in neutral or alkaline environments***

The corrosion of metals can occur in fresh water, seawater, salt solutions, and alkaline or basic media. In almost all of these environments, corrosion occurs importantly only if dissolved oxygen is present. Water solutions rapidly dissolve oxygen from the air, and this is the source of the oxygen required in the corrosion process as was shown by Nitonye *et al*. (2018). The most familiar corrosion of this type is the rusting of iron when exposed to a moist atmosphere is shown in Equation 3.

$$4Fe + 6H_2O + 3O_2 \rightarrow 4Fe(OH)_3\downarrow \quad (3)$$

In Equation 3, iron combines with water and oxygen. This combination produced an insoluble reddish-brown corrosion product that falls out of the solution, as evidenced by the downward pointing arrow in Equation 3.

During rusting in the atmosphere, there is an opportunity for drying, the ferric hydroxide dehydrates and forms the familiar red-brown ferric oxide (rust) or $Fe_2O_3$, as shown below in Equation 4 as was discovered by Sully and Taylor (2004).

$$2Fe(OH)_3 \rightarrow Fe_2O_3 + 3H_2O \quad (4)$$

Similar reactions occur when zinc is exposed to water or moist air followed by natural drying as shown in Equations 5 and 6.

$$2Zn + 2H_2O + O_2 \rightarrow Zn(OH)_2 \quad (5)$$

$$Zn(OH)2 \rightarrow ZnO + H_2O \quad (6)$$

The zinc oxide produced is the whitish deposit seen on galvanized pails, rain gutters, and imperfectly chrome-plated bathroom faucets. It also familiarly called '**white rust**' a non-protective and even destructive form of corrosion that attacks incompletely passivated galvanized steel material or galvanized components subjected to marine atmospheres.

***Subsea transmission pipelines***

It is noted (Tuaweri and Ogbonnaya, 2017; Nitonye *et al*., 2018) that transmission pipelines are large complex network of pipelines used in the transportation of natural oil and gas from one point of origin; well heads, drill stations and terminals to various distribution centers and storage facilities. Transmission pipelines are the most efficient and effective means of bulk fluid transportation as compared to rail and tanker system. Corrosion is a major hazard affecting the operational efficiency of transmission pipelines.

The dangers of pipeline failure far outweighs the cost associated with installing, monitoring, and maintaining a corrosion control system. An effective corrosion control system is the best insurance against corrosion related problems (Alawode and Ogunleye, 2011; Tuaweri and Ogbonnaya, 2017). The purpose and objectives of this work is to control external corrosion of transmission pipelines using green inhibitor such as the *Vernomia amygdalina*, determine the parameters used for measuring corrosion rate, study the effect of *Vernomia amygdalina* on mild steel and aluminum.

In the Niger Delta area of Nigeria, these pipelines crisscross the lengthen and breath of the region because of the activity of the oil exploration and exploitation by the multinational oil industries**.** Hence, we are faced with the challenge of damaging pipeline due to natural occurrence and human activities. Alawode and Ogunleye (2011) did a research on the maintenance, security and environmental implication of pipeline damage and rupture in the Niger Delta without looking at the effect of green inhibitors on subsea pipelines, while Ogbonna (2008) concentrated within the region of the South Eastern Coast of the Niger Delta in his study. This has made the authors of this work to look at the possibility of fighting corrosion with the help of green inhibitors holistically in the Region of the Niger Delta of Nigeria.

***Techniques for combating corrosion***

The Corrosion Doctor (2001) discovered three major techniques of combating corrosion, namely: material selection, environmental control, and design features. Use of corrosion inhibitors are recognized. These are chemical substances (additives) that can reduce the rate of corrosion.Inhibitors act to slow down the anodic or cathodic reaction by the formation of a protective film on the system confined in a corrosive environment to be protected. Anodic inhibitors include oxidizing agents such as nitrates, molybdates and chromates. These anions react with metal ions formed at the anode during oxidation reaction to form sparingly soluble salts. These compounds are deposited at the anode sites, forming protective films, thus preventing the anodic reactions. These inhibitors are found to be effective only when enough inhibitors are added to the corrosion medium, so that entire anodic surface can be covered.

Others are the cathodic inhibitor; these can act by inhibiting the cathodic reaction, which involves liberation of hydrogen or absorption of oxygen. They form a protective layer on the cathodic region so that evolution of hydrogen is reduced as studied by Okoroafor (2004). A good work was done by Osakuni and Abam (2004) about the Niger Delta in knowing the shallow resistivity measurement for cathodic protection of pipelines in the Delta region. Extracts of plant materials top the list. The extracts of the plants are non-toxic, environmental friendly, and always available. These extracts contain many ingredients. They have organic compounds which possess polar atoms such as O, N, P and S. They are adsorbed onto the metal surface through these polar atoms; and protective films are formed as evidenced in work of Tuaweri and Ogbonnaya (2017).

Corrosion inhibitors have limitations and disadvantages such as ability to contaminate the environment; most inhibitors are toxic in nature; can only be used in closed systems and medium with zero flow rates and finally, inhibitors lose their efficiencies with increasing concentration and temperature, which was looked at by Ekine and Emujakporue (2010) in their work, named "Investigation of corrosion of buried oil pipelines".

***The Vernonia amygdalina (VA) solution***

Several works have been done on the medical importance of the VA solution especially by Oseni and Babatude (2016) and Eraga *et al.* (2015). *Vernonia amygdalina* is a shrub or small tree that grows in tropical African region. It is also an edible plant of the Asteraceae family. It is called bitter leaf in Nigeria. Locally known as 'Ewuro' in Yoruba, 'Etidot' in Ibibio, 'Onugbu' in Igbo, 'Ityuna' in Tiv, 'Ilo' in Igala, 'Oriwo' in Edo, 'Chusar-doki' in Hausa. The leaves are green in coloration with a special odor and bitter taste. The VA is considered very medicinal and so effective against amoebic dysentery, gastrointestinal disorder, diabetes mellitus etc.

The leave of VA is used as soup condiments after washing and boiling to reduce the effect of the bitter taste. In Nigeria, it is used to prepare the popular bitter leaf soup, 'OfeOnugbu'. The leave is also made into a tonic and drank for medicinal purpose and used for traditional treatment of some disease like malaria, infertility, diabetes, gastrointestinal problems, sexually transmitted diseases, parasite related disease in animals etc. There are lots more benefits of the VA solution health wise, but this work will like to exploit the benefit of VA in the engineering field especially the Marine and Offshore Engineering.

Udochukwu *et al.* (2015) told us some bioactive compound in VA which is called the Phytochemical component of the VA solution. Table 1 shows the Phytochemical Components of ethanoic extracts of *Vernonia amygdalina* in mg/100g; while from Sodimic *et al.* (2006) and Kokwaro (2009) gave some nutritional analysis (mg/100g dry matter) of the VA which is shown in Table 2.

**Table 1: Phytochemical components of ethanoic extracts of *Vernonia amygdalina* in mg/100g**

| S/N | Phytochemicals | *Vernonia amygdalina* |
|---|---|---|
| 1 | Oxalate | 3.84 |
| 2 | Phytate | 3.95 |
| 3 | Tannins | 9.62 |
| 4 | Saponins | 5.97 |
| 5 | Flavonoid | 4.89 |
| 6 | Cyanogenic glycoside | 1.11 |
| 7 | Alkaloids | 2.16 |
| 8 | Anthraquinone | 0.14 |
| 9 | Steroid | 0.38 |
| 10 | Phenol | 3.24 |

**Source:** Odechukwu *et al.* (2015)

**Table 2: Nutritional Analysis (mg/100g dry matter) of the VA**

| S/N | Nutrient | Value |
|---|---|---|
| 1 | Crude Protein | 23.10g |
| 2 | Ash | 17.13g |
| 3 | Cellulose | 12.31g |
| 4 | Edible Portion | 100g |
| 5 | Fats | 0.4g |
| 6 | Protein | 5.2g |
| 7 | Water | 82.0g |
| 8 | Energy | 218g |
| 9 | Carbohydrate | 10.0g |
| 10 | Dietary Fibre | 1.5g |
| 11 | Calcium | 145mg |
| 12 | Phosphorus | 6.7mg |
| 13 | Iron | 5.0mg |
| 14 | Zinc | 85.0mg |
| 15 | Manganese | 710mg |
| 16 | Ascorbic Acid | 5.1mg |

**Source:** Sodimic *et al.* (2006) and Kokwaro *et al.* (2009)

With the composition in Table 2, the VA have antioxidant, Pharmacological, medicinal, Antidiabetic and antibacterial properties. This has brought some level of curiosity to know the impact of this component on human and to find out it's impact will be with respect to the offshore pipelines and structures.

**Materials and Methods**

Mild steel and aluminum sheets were used as the corrosion testing specimens. They were obtained from a fabrication store. The specimen was machined to have a large surface area to mass ratio and a small ratio of edge area to total area was used. A square specimen of dimension 35 x 30 x 1 mm shown in Fig. 1 was used. A 2.5 mm hole was bored near the top centre of the specimens. Raouf and Ahmed (2011) gave an equation to calculate the total surface area as shown in Equation 7 in their work The general equation of the Pipe to soil Potential at all humid condition

Total surface area of each specimen is given by:

$$A_s = 2(L_s B_s + B_s H_s + L_s H_s) + \left(\pi D_s H_s \frac{\pi {D_s}^2}{2}\right) \qquad (7)$$

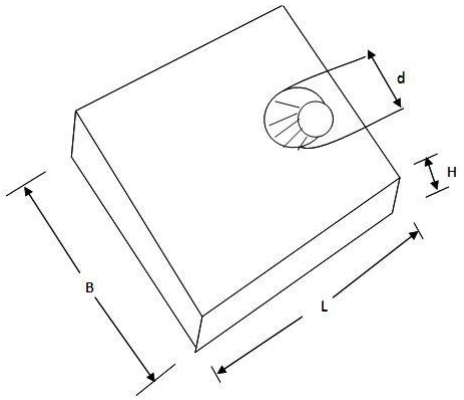


**Fig. 1: Specimen used for the experimentations**

**Where:** $A_s$ = Total area of specimen; $B_s$ = Breadth of the specimen = 30 mm; $D_s$ = Bore diameter of specimen = 2.5 mm; $H_s$ = Thickness of the specimen = 1 mm; $L_s$ = Length of the specimen = 35 mm

$$\pi = \frac{22}{7}$$

by simple substitution into Equation 7

$$A_s = 22.28 \text{ cm}$$

***Step by step procedure of the experiment***

Step by step procedures of the experiment is illustrated in Fig. 2. In Fig. 2, Step 1 to 5 is dedicated to keeping the specimens in a workable state and surface preparation of the specimen. Note that twelve specimen was used for the test as follow: 6 Aluminum; 6 mild steel samples. Step 6 to 8 is specifically associated with the preparation of the fixing of the container. Step 9 to 12 is for the preparation of the inhibitor. Step 13 to 15 is for the setup for the experiment proper. Step 16 to 22 is the setup to obtain the results for the experiment.

Step 1: All cuts and sheared edges were ground out to prevent them from becoming sites for preferential attack.
Step 2: Finishing of the specimen surface with grit abrasive paper (sand paper).
Step 3: Rinsing of the specimens in distilled water.
Step 4: Degreasing of specimen in acetone and air dried
Step 5: Upon drying, the specimen was immediately weighed to obtain their initial weights
Step 6: Holes were made at the top sides of the plastic containers
Step 7: A wooden stick placed across it
Step 8: The thread was tied through the hole in each samples and placed to the wooden sticks which were marked with their corresponding label and dipped into the corrosive medium
Step 9: 1200 g of bitter leaves was plucked, weighed and crushed
Step 10: 600 cl of water was added to the crushed leaves
Step 11: The mixture was put in a filter cloth and squeezed with hand to filter out the active concentration ingredients responsible for corrosion inhibition
Step 12: This produced a 2M concentration of *Vernomia Amygdalina* (bitter leaves) extract solution.
Step 13: Mild steel and Aluminum samples were immersed in 2 different plastic containers containing 400 ml of seawater with pH value of 7.25 with no (0%) inhibitor added to it; this serves as the control experiment.
Step 14: From the 2M bitter leaves extract solution prepared, 5% (400 ml) was measured using a measuring cylinder, then the corrosive medium seawater is poured into the measuring cylinder containing the 5% bitter leaves extract solution until the meniscus of the mixture reached the 400 ml mark and the solution was put into a plastic container. The same 5% solution was done for two different plastic containers meant for each sample-Aluminum, and mild steels.
Step 15: Each set of the specimen were looped about the wooden sticks by the aid of the rubber strings. The specimen were suspended by the strings and completely immersed in the different percentage test media. The same procedure was carried out for each of the different percentages, 10, 15, 20 and 25% and a total of 12 solutions were set up as shown in Fig. 3.
Step 16: At the end of every week (168 h) the following steps were taken to obtain readings; Removal of specimen from corrosive media, Observation and recording of appearance of the specimen noting sites and locations of deposits and variation in types of deposits.
Step 17: Cleaning of specimen with white handkerchief or tissue paper.
Step 18: Washing of specimen with distilled water.
Step 19: Scrubbing of specimen with a soft brush
Step 20: Dipping the specimen into acetone after washing.
Step 21: Removing to air-dry and weighed.
Step 22: The specimen is weighed immediately after cleaning; this is recorded as the initial weight. For each of the 12 set ups, the weight loss for each week was obtained by calculating the difference between the initial weight of each specimen and weight after immersion.

Change in Weight $\Delta W$ = (weight at time, t = 0) – (weight at time, t –i)

**Where:** i = 1-5 weeks

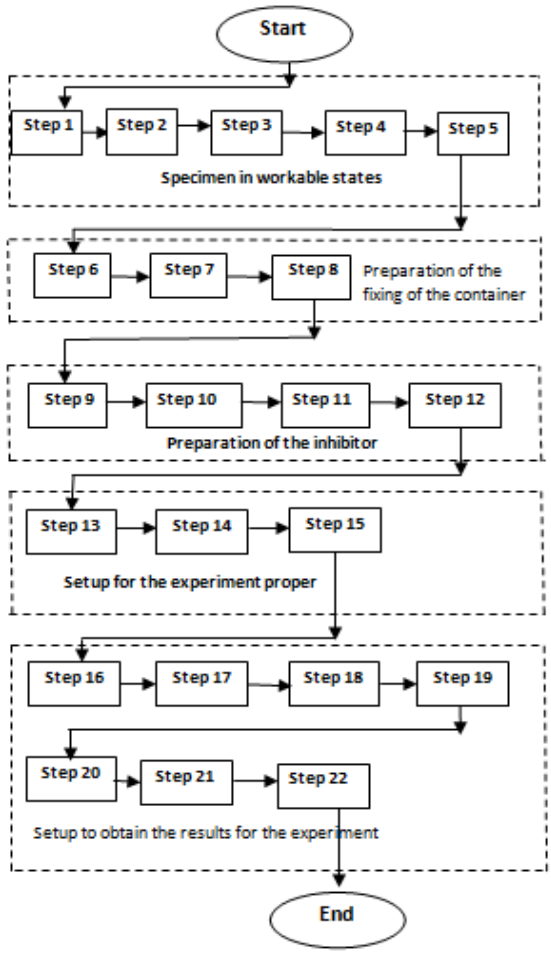


**Fig. 2: A flowchart of step by step procedure of the experiment**

**Fig. 3: Experimental setup**

***Determination of corrosion rate***

The corrosion rate is calculated from the fact that the mass loss has been used due to general corrosion and material has not been internally attacked.

The corrosion rate, CR in mm/yr is given by Equation 8 which was used by Ahmed *et al.* (2017) in their work, determination of corrosion rate of mild steel.

$$CR = \frac{K\,x\,W}{A_s\,x\,T\,x\,D_1} \qquad (8)$$

**Where:** W = mass loss (g), K = rate of corrosion = 8. 76 x $10^4$, $A_s$ = area of specimen ($cm^2$), $D_1$ = density of mild steel ($g/cm^2$) = 7.86 $g/cm^3$, T = time of exposure in hours and $D_2$=density of Aluminum ($g/cm^2$)=2.7 $g/cm^3$ (Nitonye *et. al.*, 2018).

However, the rate of corrosion is dependent on four basic functions:

- The metal specimen.
- The electrical resistance of the electrolyte.
- The amount of dissolved oxygen in the electrolyte.
- The pH value of the electrolyte.

**Results and Discussion**

Tables 3 to 12 show the results of the effect of the VA solution on the specimen at various percentage of the inhibitor with respect to the weight loss and the corrosion rate and Tables 13 and 14 serves as the control experiment. Similarly, the Figs. 4 to 13 represent the graph of corrosion rate against time and weight loss against time for Aluminum and Mild steel samples with different percentage of inhibitors (the VA solution) and Figs. 14 and 15 will serve as the control.

**Table 3: Data for WL and CR of Al sample with 5% inhibitor**

| Code | Time (hour) | Initial weight(g) | Final weight(g) | Change in weight(g) | CR (mm/yr) |
|---|---|---|---|---|---|
| **1A1** | 168 | 2.929 | 2.9181 | 0.0109 | 0.0944 |
| **1A2** | 336 | 2.929 | 2.9107 | 0.0183 | 0.0793 |
| **1A3** | 504 | 2.929 | 2.9105 | 0.0185 | 0.0534 |
| **1A4** | 672 | 2.929 | 2.9107 | 0.0183 | 0.0396 |
| **1A5** | 840 | 2.929 | 2.9114 | 0.0176 | 0.0305 |

**Table 4: Data for WL and CR of MS samples with 5% inhibitor**

| Code | Time (hour) | Initial weight(g) | Final weight(g) | Change in weight(g) | CR (mm/yr) |
|---|---|---|---|---|---|
| **1S1** | 168 | 6.6576 | 6.6321 | 0.0255 | 0.0759 |
| **1S2** | 336 | 6.6576 | 6.6239 | 0.0337 | 0.0501 |
| **1S3** | 504 | 6.6576 | 6.6149 | 0.0427 | 0.0423 |
| **1S4** | 672 | 6.6576 | 6.6127 | 0.0449 | 0.0334 |
| **1S5** | 840 | 6.6576 | 6.6103 | 0.0473 | 0.0281 |

**Table 5: Data for WL and CR of Al sample with 10% inhibitor**

| Code | Time (hour) | Initial weight(g) | Final weight(g) | Weight loss(g) | CR (mm/yr) |
|---|---|---|---|---|---|
| **2A1** | 168 | 2.9808 | 2.98 | 0.0008 | 0.006934 |
| **2A2** | 336 | 2.9808 | 2.9793 | 0.0015 | 0.006501 |
| **2A3** | 504 | 2.9808 | 2.9778 | 0.003 | 0.008668 |
| **2A4** | 672 | 2.9808 | 2.9761 | 0.0047 | 0.010185 |
| **2A5** | 840 | 2.9808 | 2.8763 | 0.0487 | 0.084426 |

**Table 6: Data for WL and CR of MS samples with 10% inhibitor**

| Code | Time (hour) | Initial weight(g) | Final weight(g) | Change in weight(g) | CR (mm/yr) |
|---|---|---|---|---|---|
| **2S1** | 168 | 6.2922 | 6.2519 | 0.0403 | 0.1199 |
| **2S2** | 336 | 6.2922 | 6.2487 | 0.0435 | 0.0647 |
| **2S3** | 504 | 6.2922 | 6.2453 | 0.0469 | 0.0465 |
| **2S4** | 672 | 6.2922 | 6.2451 | 0.0471 | 0.035 |
| **2S5** | **840** | **6.2922** | **6.2219** | **0.0703** | **0.0418** |

**Table 7: Data for WL and CR of Al sample with 15% inhibitor**

| Code | Time (hour) | Initial weight (g) | Final weight (g) | Weight loss(g) | CR (mm/yr) |
|---|---|---|---|---|---|
| **3A1** | 168 | 2.6877 | 2.6871 | 0.0006 | 0.0052 |
| **3A2** | 336 | 2.6877 | 2.6853 | 0.0024 | 0.0104 |
| **3A3** | 504 | 2.6877 | 2.6802 | 0.0075 | 0.0216 |
| **3A4** | 672 | 2.6877 | 2.6785 | 0.0092 | 0.0199 |
| **3A5** | 840 | 2.6877 | 2.6719 | 0.0158 | 0.0273 |

**Table 8: Data for WL and CR of MS samples with 15% inhibitor**

| Code | Time (hour) | Initial weight(g) | Final weight(g) | Change in weight(g) | CR (mm/yr) |
|---|---|---|---|---|---|
| **3S1** | 168 | 6.7667 | 6.766 | 0.0007 | 0.0021 |
| **3S2** | 336 | 6.7667 | 6.752 | 0.0147 | 0.0218 |
| **3S3** | 504 | 6.7667 | 6.7511 | 0.0156 | 0.0154 |
| **3S4** | 672 | 6.7667 | 6.7507 | 0.016 | 0.0119 |
| **3S5** | 840 | 6.7667 | 6.7501 | 0.0166 | 0.0098 |

**Table 9: Data for WL and CR of Al sample with 20% inhibitor**

| Code | Time (hour) | Initial weight(g) | Final weight(g) | Change in weight(g) | CR (mm/yr) |
|---|---|---|---|---|---|
| **4A1** | 168 | 2.7698 | 2.7685 | 0.0013 | 0.0112 |
| **4A2** | 336 | 2.7698 | 2.7681 | 0.0017 | 0.0074 |
| **4A3** | 504 | 2.7698 | 2.768 | 0.0018 | 0.0052 |
| **4A4** | 672 | 2.7698 | 2.7669 | 0.0029 | 0.0063 |
| **4A5** | 840 | 2.7698 | 2.7645 | 0.0053 | 0.0092 |

**Table 10: Data/values for WL and CR of MS samples with 20% inhibitor**

| Code | Time (hour) | Initial weight(g) | Final weight(g) | Change in weight(g) | CR (mm/yr) |
|---|---|---|---|---|---|
| **4S1** | 168 | 6.6391 | 6.6372 | 0.0019 | 0.0056 |
| **4S2** | 336 | 6.6391 | 6.6344 | 0.0047 | 0.0069 |
| **4S3** | 504 | 6.6391 | 6.612 | 0.0271 | 0.0268 |
| **4S4** | 672 | 6.6391 | 6.609 | 0.0301 | 0.0224 |
| **4S5** | 840 | 6.6391 | 6.589 | 0.0501 | 0.0298 |

**Table 11: Data for WL and CR of Al sample with 25% inhibitor**

| Code | Time (hour) | Initial weight(g) | Final weight(g) | Change in weight(g) | CR (mm/yr) |
|---|---|---|---|---|---|
| **5A1** | 168 | 2.8123 | 2.7036 | 0.1087 | 0.3236 |
| **5A2** | 336 | 2.8123 | 2.7204 | 0.0919 | 0.1368 |
| **5A3** | 504 | 2.8123 | 2.7175 | 0.0948 | 0.0941 |
| **5A4** | 672 | 2.8123 | 2.7003 | 0.112 | 0.0834 |
| **5A5** | 840 | 2.8123 | 2.7001 | 0.1122 | 0.0668 |

**Table 12: Data for WL and CR of MS samples with 25% inhibitor**

| Code | Time (hour) | Initial weight(g) | Final weight(g) | Change in weight(g) | CR (mm/yr) |
|---|---|---|---|---|---|
| **5S1** | 168 | 6.5976 | 6.5963 | 0.0013 | 0.0038 |
| **5S2** | 336 | 6.5976 | 6.5925 | 0.0051 | 0.0075 |
| **5S3** | 504 | 6.5976 | 6.5917 | 0.0059 | 0.0058 |
| **5S4** | 672 | 6.5976 | 6.59 | 0.0076 | 0.0056 |
| **5S5** | 840 | 6.5976 | 6.589 | 0.0086 | 0.0051 |

**Table 13: Data for WL and CR of Al sample with 0% inhibitor**

| Code | Time (hour) | Initial weight(g) | Final weight(g) | Change in weight(g) | CR (mm/yr) |
|---|---|---|---|---|---|
| **6A1** | 168 | 2.8465 | 2.7474 | 0.0991 | 0.859 |
| **6A2** | 336 | 2.8465 | 2.6775 | 0.169 | 0.7324 |
| **6A3** | 504 | 2.8465 | 2.6353 | 0.2112 | 0.6102 |
| **6A4** | 672 | 2.8465 | 2.631 | 0.2455 | 0.5319 |
| **6A5** | 840 | 2.8465 | 2.5903 | 0.2562 | 0.4441 |

**Table 14: Data for WL and CR of MS samples with 0% inhibitor**

| Code | Time hour | Initial weight(g) | Final weight(g) | Change in weight(g) | CR (mm/yr) |
|---|---|---|---|---|---|
| **6S1** | 168 | 6.8217 | 6.6139 | 0.2078 | 0.6187 |
| **6S2** | 336 | 6.8217 | 6.612 | 0.2097 | 0.3122 |
| **6S3** | 504 | 6.8217 | 6.5345 | 0.2872 | 0.2872 |
| **6S4** | 672 | 6.8217 | 6.531 | 0.2907 | 0.2164 |
| **6S5** | 840 | 6.8217 | 6.5117 | 0.31 | 0.1846 |

Figures 4 and 5 represent the graph of corrosion rate against time and weight loss against time for Aluminum and Mild steel samples with 5% inhibitor. It is observed that at week one of exposure to corrosive medium there was a substantial reduction in weight of the specimen but over the weeks there was a gradual decline in weight loss and the corrosion rate reduced evenly. Although the medium is inhibited, there is still a good percentage of corrosion of specimen.It is obverse that the percentage of inhibitor to corrosive medium (seawater) is insufficient. Figs. 6 to 9 show the graph of corrosion rate against time and weight loss against time for Aluminum and Mild steel samples with 10 and 15% inhibitor, respectively.

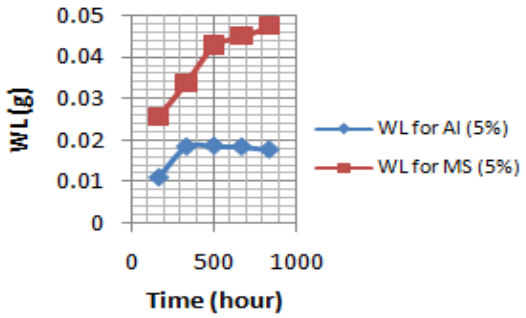


**Fig. 4: Weight loss for AL and MS of 5% VA**

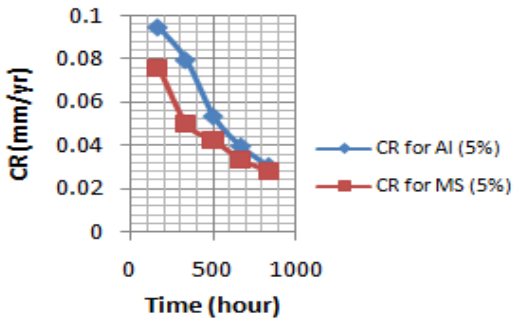


**Fig. 5: Corrosion rate for AL and MS of 5% VA**

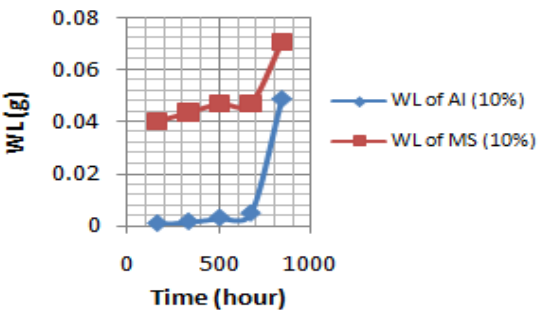


**Fig. 6: Weight loss for AL and MS of 10% VA**

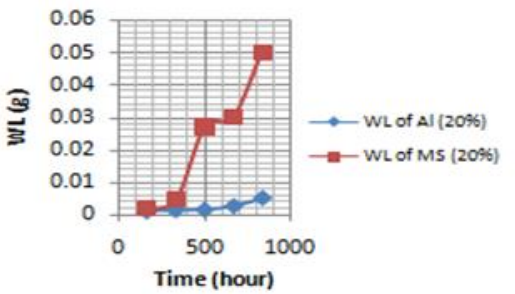


**Fig. 7: Corrosion rate for AL and MS of 10% VA**

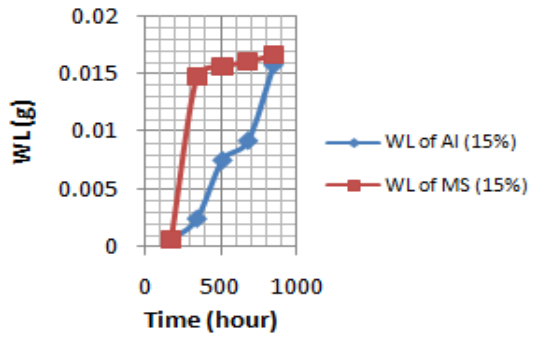


**Fig. 8: Weight loss for AL and MS of 15% VA**

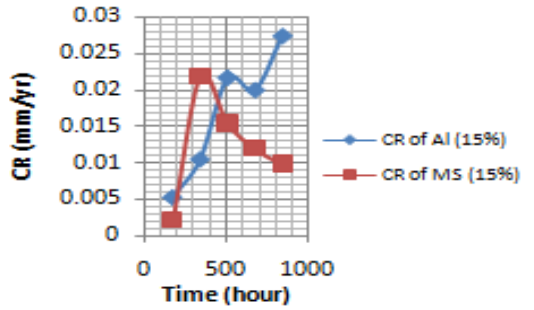


**Fig. 9: Corrosion rate for AL and MS of 15% VA**

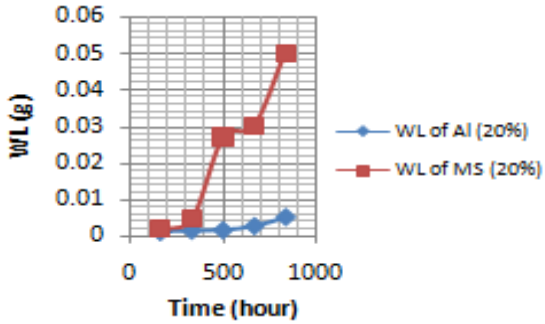


**Fig. 10: Weight loss for AL and MS of 20% VA**

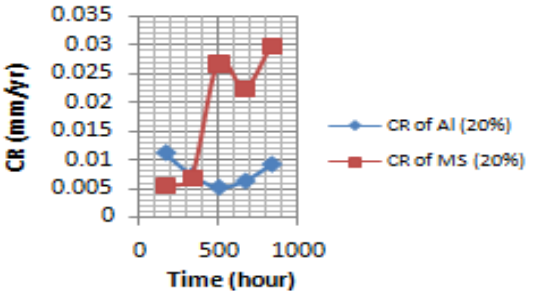


**Fig. 11: Corrosion rate for AL and MS of 20% VA**

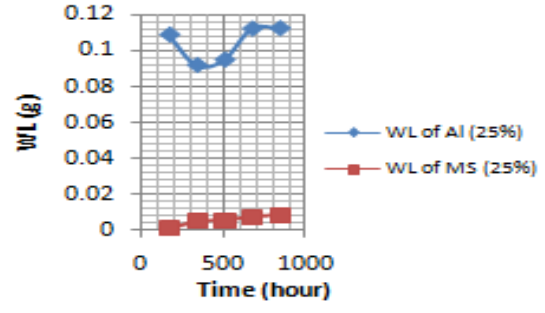


**Fig. 12: Weight loss for AL and MS of 25% VA**

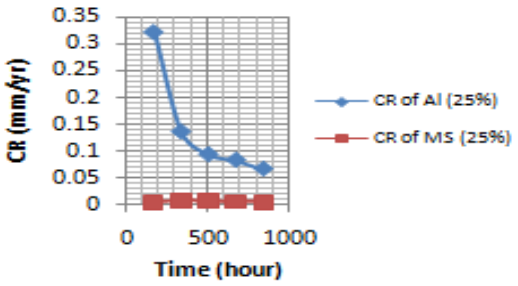


**Fig. 13: Corrosion rate for AL and MS of 25% VA**

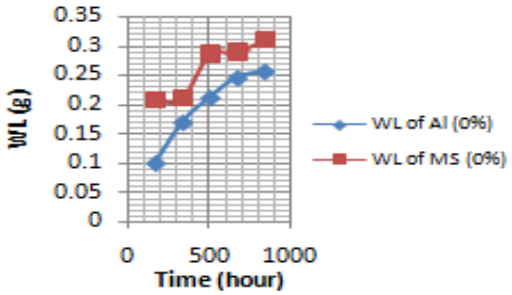


**Fig. 14: Weight loss for AL and MS of 0% VA**

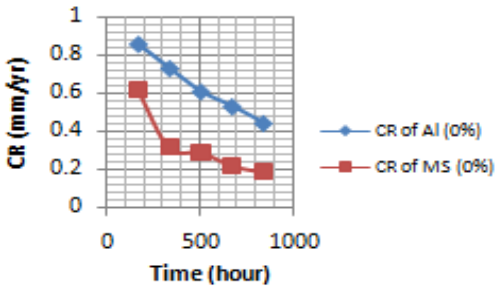


**Fig. 15: Corrosion rate for AL and MS of 0% VA**

This shows that there is an effective control of corrosion in the coupons over the period of the experiment. It represents an optimal inhibiting process to a great extent. Figs. to 13 show the graph of corrosion rate against time and weight loss against time for Aluminum and Mild steel samples with 20 and 25% inhibitor, respectively. It is observed that the last two weeks of the experiment there is a great decrease in corrosion rate. This explains that even with increasing percentage of inhibitor, the corrosion rate is not reduced correspondingly. So a right percentage of inhibitor needs to be administered. Figs. 14 and 15 represent the graph of corrosion rate against time and weight loss against time for Aluminum and Mild steel samples with 0% inhibitor, respectively. This is the control solution; the samples are vulnerable to corrosion.

**Conclusion**

It is observed that when the VA Solution is introduced into the corrosive medium, it reacts in a way to neutralize the acidic environment to form a soluble salt thereby retarding the corrosive process on the specimen. So, it can be stated that the VA solution is an anti-corrosion solution especially for subsea transmission pipeline. By this investigation it was observed that during the first week when the concentration of the VA solution is high there was an optimum inhibition up to 25% on the material but by the fifth week, the inhibitor was gradually losing its effectiveness. This means if the effectiveness and the concentration of the inhibitor is maintained through the year the VA solution will reduce corrosive tendency of the environment. From the graphs is concluded that the Al sheet exhibit a good degree of tolerance in the VA solution

compared. The research work also shows that proper corrosion programme, monitoring technique and installation of pipeline should be studied and implemented especially when using organic inhibitors like the VA solution. Knowing that the organic inhibitors loss their properties and effectiveness with time. Further research work can be done considering a flowing corrosive environment and with a high temperature, this because this work was done at room temperature and zero flow rate of both the inhibitor and the corrosive environment.

**Conflict of Interest**

Authors declare that there is no conflict of interest related to this paper.

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