

# **STUDIES OF THE INHIBITIVE/ADSORPTIVE BEHAVIORS OF *Costus afar* LEAVES EXTRACT ON THE GROWTH OF SULPHUR REDUCING BACTERIA AND ANAEROBIC CORROSION OF PIPELINE STEEL CAUSED BY SULPHUR REDUCING BACTERIA**

## **Abstract**

The inhibitive/adsorptive behavior of *Costus afar* leaves extract on the growth of sulphate reducing bacteria and anaerobic corrosion of pipeline steel caused by sulphate reducing bacteria were studied using gravimetric and media absorbance examination techniques. The test organism *Desulphurivibrio specie* was isolated from corroded pipe line steel supplied by *Alteleriae Deonstriea Materae* Nigeria ltd. Postgate medium was used for the isolation of the organism, and the coupons used for the study were prepared from the rusted pipe line steel. The results of the absorbance of the media studied showed decrease in absorbance of the media containing *Costus afar* leaves extract from the absorbance of the blank uninhibited medium. The decrease in the absorbance level has been suggested to be attributed to inhibition of Sulphate reducing bacteria in the inhibited media which resultantly led to light passing through with less interactions than the absorbance observed in the blank medium. The gravimetric results showed decrease in weight loss and corrosion rate in the medium containing *Costus afar* leaves extract from the blank, and the decrease in corrosion rate was more pronounced as the concentration of the *Costus afar* leaves extract increased in the media. Inhibition efficiency of the plant extract increased with increase in extract concentration. Besides obstructing of the metabolic process of the microbial influenced corrosion agents (sulphate reducing bacteria), the plant extract molecules got absorbed to the pipeline steel surface serving as a protective shield against the invading microbial influenced corrosion agents (sulphate reducing bacteria). Adsorption of the extract molecules fitted into Langmuir adsorption isotherm.

Key words: Anaerobic corrosion, *Desulphurivibrio specie*, Corrosion inhibition, Postgate medium, *Costus afar*.

## 1.0 INTRODUCTION

**Corrosion** is the deterioration or degradation of metals or alloys, when they are destructively attacked by their environment. It is an electrochemical process which generally occurs in the presence of oxygen, aqueous electrolyte solution and moisture. (Chernova *et al*, 1978). It could be over the entire surface of a metal or alloy, and it occurs electrochemically between two different metallic materials or between two points on the surface of alloys of different chemical activity (Potgieter, 2010). Besides aerobic environs corrosion also occurs in anaerobic environments like buried pipe lines. This anaerobic corrosion is caused and influenced by microorganisms present in biofilms. The microorganism's ability to utilize these metals as a source of carbon and energy required for their growth and metabolism using products of their metabolic activities such as enzymes, exopolymers, organic and inorganic acids, as well as ammonia and hydrogen sulphide, leads to deterioration and failure of pipes (Oyewole *et al.*, 2011).

Microbiologically influenced corrosion (MIC) or bio-corrosion is a considerable problem for the oil and gas industry (Korenblum *et al* 2013). It is considered one of the most damaging mechanisms to pipeline steel materials. (Korenblum *et al* 2010). Microorganisms are thought to be responsible for greater than 20% of pipeline systems failures (Javaherdashti, 2008). The main types of bacteria associated with metals in pipeline systems are sulfate-reducing bacteria (SRB), iron reducing bacteria, CO<sub>2</sub> reducing bacteria, iron oxidizing bacteria and manganese oxidizing bacteria (Little and Lee, 2007; Javaherdashti, 2008 ). Among these, sulfate reducing bacteria have received much attention in the oil and gas industry and microbial influenced corrosion. However, investigations have shown that these micro-organisms have several detrimental metabolic activities including ability to;

- Oxidize hydrogen as an electron donor for metabolic life (Little *et al.*, 2007 Javaherdashi, 2008)
- use O<sub>2</sub> and Fe<sup>3+</sup> as a terminal electron acceptor (Hamilton, 1985)
- Utilize aliphatic and aromatic hydrocarbons as a carbon source (Rueter *et al.*, 1994)
- use very low levels of water for cellular maintenance and growth (Enning and Garrets 2013)
- couple sulfate reduction to the intracellular production of magnetite ( Videla 2001)
- compete with nitrate-reducing bacteria /sulfur-oxidizing bacteria (NRB–SOB) (since they may have a nitrite reducing activity) (Greene *et al.*, 2003; Miranda, *et al.*, 2006)
- Cause elemental oxidation of iron (Yuan *et al* 2013)

Basically, prevention and treatment of microbial influenced corrosion is aimed mainly at destroying the microbial cell and/or preventing the development of biofilms (Guiamet and Saravia, 2005).

Hydrocarbons in petroleum may serve as electron donors for sulfate reducing bacteria (SRB), which use sulfate as the terminal electron acceptor for respiration, resulting in sulfide production. The biogenic sulfide production results in metal bio-corrosion and SRB are typically the main bacterial group involved in these harmful processes in petroleum industries. The biogenic hydrogen sulfide production causes the bio-corrosion of metal surfaces of pipelines and tanks (Nemati *et al.*, 2001a). Moreover, the sulfide is explosive in high concentrations. SRB may grow in pipes and tanks forming biofilms, leading to the biodegradation of the metal surface (Zuo, 2007). Finally, the accumulation of SRB biomass causes reduced oil recovery (Muyzer and Stams 2008; Nemati *et al.*, 2001b; Postgate, 1965). Therefore, in petroleum industries, it is mandatory to control and inhibit SRB growth, which is usually done by biocide dosage

(Korenblum *et al.*, 2010; Videla, 2002). Regardless of the effectiveness of these biocides, antimicrobial resistance often occurs, particularly in biocide treated biofilms (Stewart and Costerton, 2001; Fraise, 2002). In addition, the residual concentration, toxicity and persistence of biocides in industrial effluents are of high environmental concern. Hence, alternatives for SRB control are of great interest to the petroleum industry (Nemati *et al.*, 2001b; Stewart, 2002).

Less expensive and environmental friendly treatments are sought by the petroleum industry as alternatives to the use of synthetic biocides. Essential oils from plant extracts are mixtures of lipophilic and volatile substances, which are known to have components with antibacterial and/or antifungal activity, and are potential sources of novel inhibitory substances (Hammer *et al.* 1999; Solórzano-Santos and Miranda-Novales, 2012). The composition of essential oils/phytochemicals is different among species and plant parts. The oil's main components are terpenes and terpenoids, which are aromatic and aliphatic acid, esters and phenolic compounds (Reichling *et al.* 2009). The effect of different plant extracts on biofilms has already been demonstrated in the food industry and medical devices. (Videla, 2001). In addition, unlike other natural antimicrobial compounds, essential oils show inhibition on planktonic and sessile microbial growth at the same concentration. Thus, the ability to form biofilms does not provide extra protection for the organism when using essential oils as an antimicrobial agent (Nuryastuti *et al.* 2009; Nahle *et al.* 2010; Adukwu *et al.* 2012; Kavanaugh and Ribbeck 2012) These reasons spur our interest and suggestion that *Costus afar* plant will possess good microbial influenced corrosion inhibition properties since it possesses antibacterial and/or antifungal activity and it is a potential source of novel inhibitory substances (Hammer *et al.*, 1999; Solórzano-Santos and Miranda-Novales, 2012).

### 1.1 *Costus afar* as Microbial Influenced Corrosion Inhibitor

The plant *Costus afar* is among the 150 species of stout, perennial and rhizomatous herbs of the genus *Costus*. It can be found in the forest belt of Senegal, South Africa, Guinea, Niger, Sierra Leone and Nigeria (Burkill, 1985; Edeoga and Okoli., 2000). *Costus afar* is commonly called bush cane or by other names in the Nigerian languages viz: Ireke omode (Yoruba), Opete (Igbo), Mbriem (Efik/Ibibio). *Costus afar* contains several bioactive metabolites (Stentoft, 1988), hence its extensive use in folkloric medicine as remedy for cough, rheumatic pains, sleepiness and cardio tonic. Tea from the dried aerial parts is used for hypertension while the leaves are used as poultry feed additives to increase both the size and number of eggs of treated birds. (Edeoga and Okoli, 2000). Studies on different parts of *Costus afar* reveal invitro and invivo pharmacological activities (Anaga *et al.*, 2004), essential oil, topical anti-inflammatory activity, phytochemical composition and antioxidant activities (Anyasor *et al.*, 2010), antimicrobial activity (Akpan *et al.*, 2012). A few chemical studies have shown that *Costus afar* contains oxalic acid, lanosterol, trigogenin, new diosgenin, stigmasterol, Sitosterol, costugenin, a new steroidal saponin aferoside. (Stentoft, 1988). The corrosion inhibition potentials of *Costus afar* on mild steel in acidic medium have also been reported (Ibisi and Anyanwu 2015). The present study investigates the inhibitive/adsorptive behaviors of *Costus afar* leaves extract on the growth of sulphate reducing bacteria and anaerobic corrosion of pipe line steel caused by sulphur reducing bacteria.

## 2.0 MATERIALS AND METHOD

### 2.1 Collection and Identification of Sample

The sample was collected from the plant of interest around Michael Okpara University of Agriculture Umudike, Umuahia, Abia state, and was identified by Professor G.G.E Osuagu from

the department of Plant Science and Biotechnology, college of Natural and Applied Science, Michael Okpara University of Agriculture, Umudike, Abia state, Nigeria.

## **2.2 Sample preparation and Extraction**

The sample *Costus afar* leaves were spread out on a laboratory work bench and inspected for the presence of extraneous materials such as dirt and insects larva. The inspected sample was cut into pieces to increase the surface area for easy drying. It was then further oven dried at a temperature of 50°C and pulverized to powdery form. The Extraction was carried out as discussed by (Oyewole *et al.*, 2012). About a hundred grams of the powdered sample in one liter of distilled water was extracted using a soxhlet extractor for twenty four hours. The extract was then concentrated using a rotary evaporator.

## **2.3 Media preparation**

Postgate medium was used for the isolation of the test organism and this was compounded from 0.5g Potassium phosphate ( $K_2HPO_4$ ), 2g Sodium Chloride (NaCl), 1g Sodium Sulphate ( $Na_2SO_4$ ), 0.1g Calcium Chloride ( $CaCl_2$ ), 3.5g Sodium Lactate ( $CH_3CHOHCOONa$ ), 0.0002g Iron (ii) Sulphateheptahydrate ( $FeSO_4 \cdot 7H_2O$ ), 1g Yeast extract, 1litre of distilled water, sterilized at 121°C for fifteen to twenty minutes, (Oyewole *et al.*, 2012).

## **2.4 Isolation of *Desulphovibrio* specie**

*Desulphovibrio* specie was isolated from corroded pipe line steel supplied by the *Atelerie Deconstreae Materea* Limited, an oil servicing company located at Trans Amadi Industrial Layout, Portharcourt, Rivers State, Nigeria. The corroded sample was collected into a sterile sample bottle and brought into microbiology laboratory of Michael Okpara University of Agriculture Umudike, Umuahia, Abia state, Nigeria. The corroded pipe was immersed in sterile water for twenty four hours and a sample of the water was collected from it for analysis. Five

folds serial dilution was then carried out using the water sample and these were placed on a freshly prepared Postgate agar and incubated anaerobically at 37°C for three days. One milliliter of pure isolate was sub-cultured into nine milliliter of Postgate broth and incubated anaerobically at 37°C for three to five days, (Cowan and Steel, 1974; Cheesbrough, 2003; Oyewole *et al.*, 2012).

## **2.5 Preparation of the Steel into Steel into Coupons**

The corroded steel provided was sandpapered at the department of Metallurgy, Federal University of Technology Owerri, Imo state, Nigeria, and was further cut into

The coupons were washed with distilled water and dried in acetone. The dried coupons were weighed and stored in air tight desiccators prior to use.

## **2.6 Determination of Effect of *Costus afar* extract on Test Organism.**

Nine milliliters of Postgate broth was dispensed into seven test tubes and the plant extract was introduced into each of the test tubes in different concentrations (10mg/ml, 50mg/ml, 200mg/ml, 300mg/ml, 400mg/ml and 500mg/ml). A Control was also set up, without the plant extract. A piece of the pre-weighed coupons was then introduced into each of the test tubes containing various concentrations the plant extract and the blank respectively. The medium was sterilized with an autoclave at 121°C for fifteen to twenty minutes after which one milliliter of the pure isolate was inoculated into the test tubes and the experiment was setup for thirty days in anaerobic jar. The temperature of the medium was maintained at 37°C throughout the duration of the experiment. The rate of corrosion was then determined using weight loss method.

## **2.7 Weight Loss Method**

The pre-weighed coupons immersed in the various test tubes were retrieved after thirty days and the weight loss was measured and calculated using equation 2.1.

Where,  $\Delta W$  is the weight loss,  $W_1$  is the weight of coupon before the immersion,  $W_2$  is the weight of the coupon after immersion. From the weight loss data, the corrosion rates of the coupons were calculated with the formula in equation 2.2

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Where;  $CR$  is the rate of corrosion,  $A$  is the area of the coupon,  $\Delta W$  is the weight loss,  $t$  is the time of immersion.

The inhibitory efficiency and the degree of surface coverage of *Costus afar* plant extract on the corroded steel were calculated from the corrosion rate data, using equations 2.3 and 2.4;

$$\left( \frac{\quad}{\quad (—)} \right)$$

$\theta$  is the degree of surface coverage, IE is the inhibitory efficiency,  $CR_{in}$  is the corrosion rate in inhibited system,  $CR_{bl}$  is the corrosion rate in non-inhibited system.

### 3.0 RESULT AND DISCUSSION

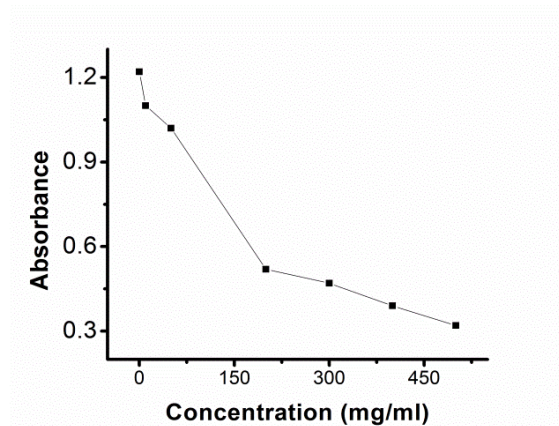
#### 3.1 MICROBIAL INHIBITION

The effect of *Costus afar* extract on the growth of *Desulphovibrio species* is evident in the absorbance shown by the medium containing the plant extract in different concentrations compared with that of the blank. The result is graphically represented in figure 1, which is a plot



of absorbance against concentration of the media studied. Observations from the graph depicts a decrease in the absorbance of the media containing *Costus afar* leaves extract, from that shown by the blank. The decrease in absorbance became more pronounced as the concentration of the plant extract increased from 10mg/ml to 500mg/ml. The reason for this decrease in absorbance no doubt is likely to be that there was more growth of *Desulphobrio sp.* in the blank, while the less growth of the bacteria in the media containing the plant extract resulted in more light passing through the medium. It can also be observed that the absorbance decreased more as the concentration of the extract increased from 10mg/ml to 500mg/ml which simply means that the inhibition increases as the concentration of *Costus afar* leaves extract increase.

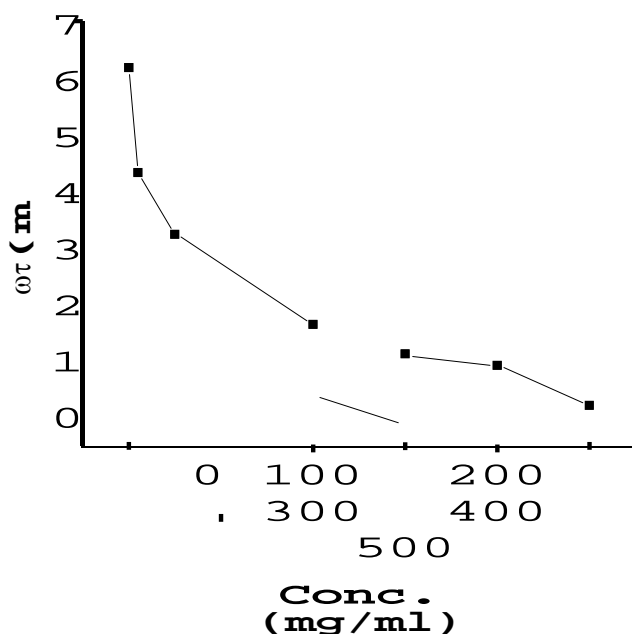
*Desulphobrio sp* influence corrosion by reducing sulphates, to sulphide compounds. (Enning and Garrets 2014). The sulphide thus formed, reacts with iron in pipes to form iron (II) sulphide – a corroded product (Beech and Sunner, 2004; Oyeleke *et al.*, 2005; Beech and Gaylarde, 2008; Oyewole, 2011; Kakooei *et al.*, 2012). Besides the inhibition of the growth of sulphur reducing bacteria, the extract can as well get absorbed to the metal surface and form a barrier layer on the water pipes which serves as protective shield against the invading microbial thereby preventing corrosion. (Beese *et al* 2013).



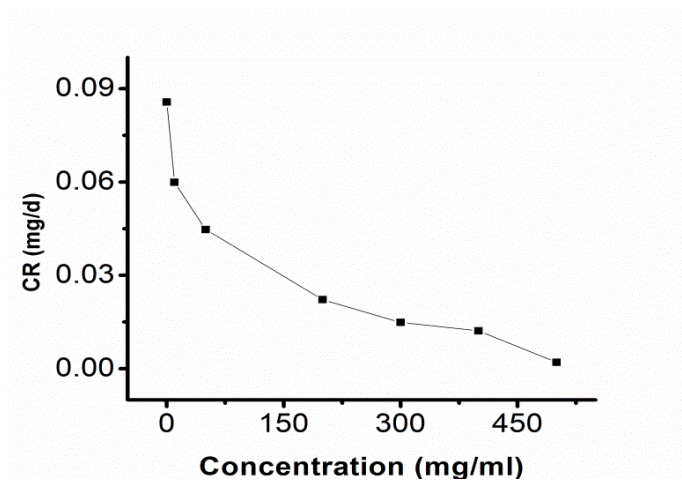
**Figure 1: Plot of Absorbance against concentration of the media**

### 3.2 Gravimetric Results

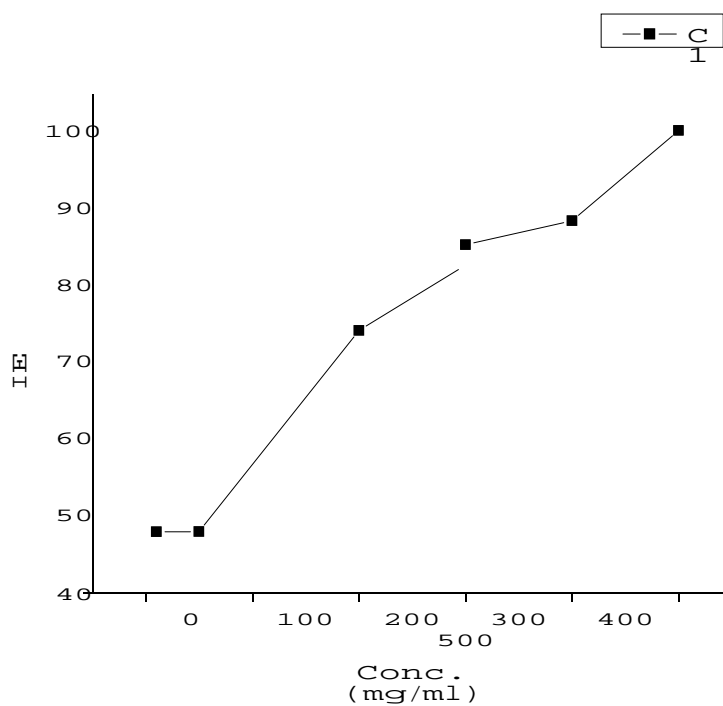
The weight loss results of the blank (control) and the inhibited medium is graphically represented in figure 2. Observations from the graph show decrease in weight loss as the concentration of *Costus afar* leaves extract increase from 10mg/ml to 50mg/ml. The graphical representation of corrosion rate of the iron pipe in anaerobic microbial influence corrosion is depicted in figure 3. A study of the graph shows that corrosion rate decreased in presence of the plant extract and this effect became more pronounced with increase in the concentration of the *Costus afar* leaves extract. This decrease in corrosion rate shown means that, the plant extract inhibited microbial influenced corrosion caused by sulphate reducing bacteria in anaerobic medium. This observation is related to what was observed in (Oyewole *et al.*, 2012), from their study on inhibitory effect of nicotine on corrosion caused by *Desulphovibro specie* isolated from water pipes in Minna Nigeria



**Fig 2: Plot of weight loss against concentration of *Costus afar***



**Fig 3: Corrosion rate against concentration of *Costus afar***

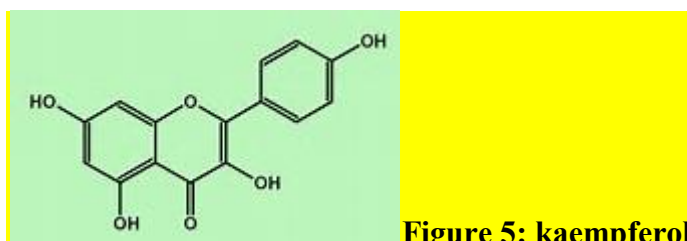


**Fig 4: Inhibition efficiency against concentration of *Costus afar***

Figure 4 shows graphical representation of inhibition efficiency of *Costus afar* leaves on

corrosion caused by *Desulphovibrio sp.* in anaerobic medium. Observation from the graph shows

increase in inhibition efficiency as the extract concentration increases from 10mg/ml to 500mg/ml. This inhibition could be as a result of the extract molecules absorption to the surface of the pipe line steel and, or the inhibition on the growth of sulphate reducing bacteria by the plant extract. (Oyewole *et al.* 2011). Studies carried out previously on *Costus afar leaves*, by (Omokhua ,2011, and Ikpeazu *et al.*, 2016). *Costus afar* leaves extract is constituted of organic compounds like kaempferol, (2-Aziridinyethyl) amine, 3-flouro- $\beta$ ,5 -dihydroxyl-N-methyl benzeethanamine, Dextroamphetamine, Hydroxyurea, Epinephrine etc, with structures in the figures below.



**Figure 5: kaempferol**



**Figure 6:(2-Aziridinyethyl) amine**

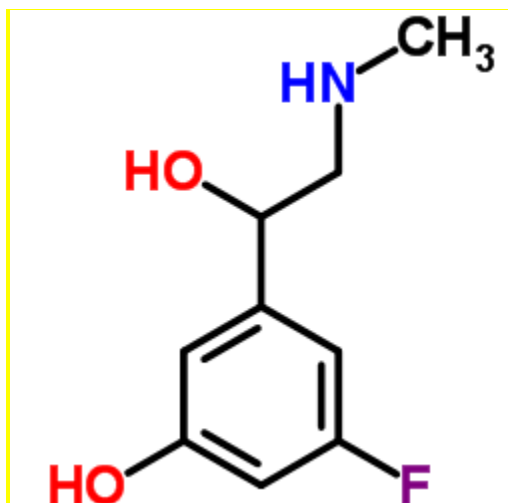


Figure 7: 3-flouro-β ,5 -dihydroxyl-N-methyl benzeethanamine

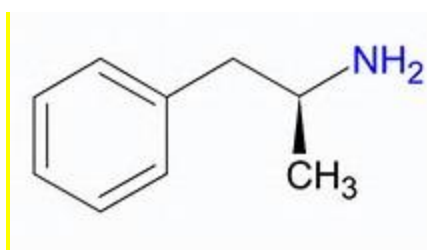


Figure 8:Dextroamphetamine

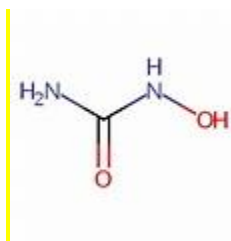


Figure 9: Hydroxyurea

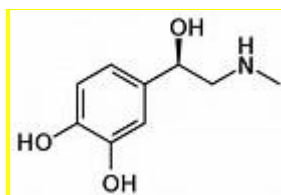


Figure 10: Epinephrine

Since *Costus afar* leaves extract contains so many compounds with amine, hydroxyl, carbonyl and floro functionalities, which ligands and can therefore form complexes with the metal surface thereby getting adsorbed to the metal. (Ibisi *et al* 2015. It is then difficult to single out the compound that is responsible for the adsorption of the plant extract on the metal surface.

However more than one compound if not all, that contain functional groups with hetero atoms can take part in the adsorption/ inhibition of sulphate reducing bacteria.

### 3.3 ADSORPTION CONSIDERATION

The relationship between the degree of surface coverage and *Costus afar* leaves extract can be represented by the Langmuir adsorption isotherm as stated in equation 3.1

$$\theta = \frac{K_{ad} C}{1 + K_{ad} C}$$

Where  $C$  is the concentration of the plant extract,  $\theta$  is degree of surface coverage and  $K_{ad}$  is the constant for adsorption. The equation is related to free energy at adsorption ( $\Delta G^0_{ad}$ ) by the expression in equation 3.2

$$\Delta G^0_{ad} = -RT \ln K_{ad}$$

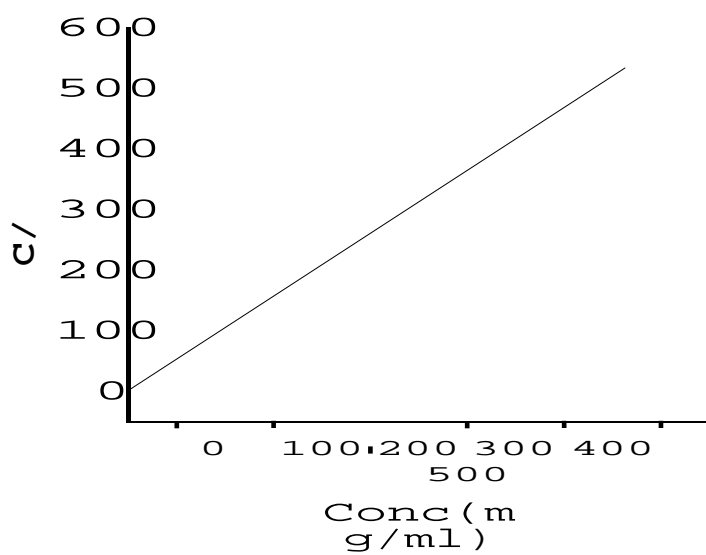
Where,  $T$  is temperature,  $R$  is gas constant and other parameters retain their previous definition.

Figure 11 shows the plot of  $C/\theta$  against concentration of the *Costus afar* leaves extract to be linear with intercept  $1/K$  which suggest that the experiment fits into Langmuir adsorption isotherm. The calculated values of free energy of adsorption are shown in table 2. The negative sign observed in the values obtained in 200mg/ml, 300mg/ml and 400mg/ml indicates that *Costus afar* leaves extract molecules was spontaneously adsorbed to the pipe line steel surface in these concentrations of the plant extract in the anaerobic corrosive medium studied. (Ngobiri *et al* 2015) In contrary extract concentrations of 10mg/ml, 50mg/ml and 500mg/ml showed positive values which indicates that adsorption is not spontaneous and has to be induced in these concentrations (Ibisi and Uwakwue, 2015).



**Table 2: Results of Free Energy of Adsorption**

Concentration (mg/ml)	Free energy( $\Delta G^0_{ad}$ ) KJ/mol
10	2.2468
50	0.0462
200	-0.5948
300	-0.3329
400	-0.4629
500	3.8301



**Fig 11: Langmuir absorption isotherm**

## CONCLUSION

From the results of the analysis carried out, it can be concluded that;

- i. *Costus afar* leaves extract inhibits the growth of sulphate reducing bacteria and corrosion caused by the bacteria in anaerobic medium.
- ii. The inhibition efficiency increases as the concentration of the plant extract increases.
- iii. The microbial influenced corrosion inhibition by the plant extract was as a result of the inhibition of the growth of the *Desulphovibrio sp.* and or the adsorption of the plant extract molecules on the surface of the metal.
- iv. *Costus afar* leaves extract spontaneously adsorbed to the pipe line steel surface and the adsorption fitted into Langmuir adsorption isotherm

### References

- Adukwu E.C, Allen S.C.H., Phillips C.A (2012), The anti-biofilm activity of lemongrass (*Cymbopogon flexuosus*) and grapefruit (*Citrus paradisi*) essential oils against five strains of *Staphylococcus aureus*. *J Appl Microbiol* 113(5):1217–1227.
- Akpan, M.M., Odeomena, C.S., Nwachukwu, C. N., Danladi, B. (2012). *Asian journal of plant science and research*, 2, (3): 335-341.
- Anaga A.O., Njoku, C.J., Ekejiuba, E.S., Esiaka, M.N. and Asuzu, I.U. (2004) Investigations of the methanolic leaf extract of *Costus afar*. Ker for pharmacological activities in vitro and in vivo. *Phytomedicine* 11, 242-248.
- Anyasor G.N., Ogunwenmo, K.O., Oyelana, O.A., Akpofunure, B.E. (2010). phytochemical constituents and anti oxidant activities of aqueous and ethanolic extracts of *Costus afar*, *African Journal of Biotechnology*, 9 (31): 4880-4884.
- Beech I.B., Sunner, J. (2004). Biocorrosion: Towards understanding interaction between biofilms and metals. *Journal of Current Opinion in Biotechnology*, 15:181-186.
- Beech I. B., Gaylarde, C. C. (2008). Recent Advances in the study of biocorrosion an overview. *Revista de microbiologia* 30 (1): 77-190.
- Beese, P., Venzlaff, H., Srinivasan, J., Garrelfs, J., Stratmann, M. and Mayrhofer, K.J.J. (2013). Monitoring of anaerobic microbially influenced corrosion via electrochemical frequency modulation. *Electrochim. Acta* 105:239–247.
- Burkill, H.M. (1985). The useful plants of West Tropic al Africa: Rev Dalziel's J.M. Royal Botanical Gardens Kew. 2nd ed. Families A-D., 1:135-191.

- Cheesbrough M. (2003). District laboratory practical in tropical countries low priced edition. Cambridge University Press, England.
- Chernova G. P., Tomashov N. D., Chigirinskaja L. A., (1978), The Effect to Alloying on the Passivation of Iron-Chromium-Based Alloys, *corr*,34; (12): 445-446.
- Cowan, S. T., Steel, K.J. (1993). Manual for the Identification of Medical Bacteria (2nd Edition). Cambridge University Press, London.
- Edeoga, H.O., Okoli, B.E., (2000), chromosome number of *Costus lucanusianus* (costaceae) *Folia Geobotanica* , 35(3) 315-318.
- Enning D. and Garrets J., (2014), Corrosion of Iron by Sulfate-Reducing Bacteria: New Views of an Old Problem, *AEM*, 80: (4), 1226-1236
- Fraise, A.P. (2002) Biocide abuse and antimicrobial resistance a cause for concern? *Antimicrob Chemother*, 49:11–12.
- Greene, E.A., Hubert, C., Nemati, Jenneman, G.E., Voordouw, G. (2003). Nitrite reductase activity of sulphate reducing bacteria prevents their inhibition by nitrate reducing, sulphide-oxidizing bacteria. *Environ Microbiol*, 5(7):607–17.
- Guiaimet, P.S., Gomez de Saravia, S.G. (2005). Laboratory studies of biocorrosion control using traditional and environmentally friendly biocides: an overview. *Latin Am Appl Res.*, 35(4):295–300.
- Hammer K.A., Carson C.F., Riley T.V (1999) Antimicrobial activity of essential oils and other plant extracts. *J Appl Microbiol* 86:985–990
- Hamilton, W.A. (1985). Sulfate-reducing bacteria and anaerobic corrosion. *Annu Rev Microbiol*, 39:195–217.
- Ibisi N. E., and Anyanwu B. (2015) *Costus afar* extract as a sustainable inhibitor of mild steel corrosion in aggressive environment. *International Journal of Applied Research and Technology* 4(7): 110 – 117.
- Ibisi N. E., Okoroafor D. O. And Ogu C., (2015), *Voacanga africana* as green inhibitor of corrosion of mild steel in corrosive environment. *Time Journals of Engineering and Physical Sciences.*, 3, 1:63-69.
- Ibisi, N.E., Uwakwue, V.I. (2015). *Cnestis ferruginea* as eco-friendly corrosion inhibitor of mild steel in corrosive environment. *Global journal of environmental science and technology*, 2(6):355-359.
- Ikpeazu U.J.M., Ikpa C.B.C., and Osondu M.C., (2016) Preliminary study on the pharmaceutical constituents of methanol extract of *Custus afar* , *International Dixgital Journal of Experimental Science*, 1(1 ): 21-30
- Javaherdashti R. (2008), Microbiologically influenced corrosion – an engineering insight. London: Springer-Verlag

- Kakooei, S., Ismail M.C., Ariwahjoedi, B. (2012). Mechanisms of microbiologically influenced corrosion: A review, *World Applied Sciences Journal*, 17(4): 524-531.
- Kavanaugh N.L, Ribbeck K., (2012) Selected antimicrobial essential oils eradicate *Pseudomonas* spp. and *Staphylococcus aureus* biofilms. *Appl Environ Microbiol* 78:4057–4061. doi:10.1128/AEM.07499-11
- Korenblum, E., Valoni, E., Penna, M., Seldin, L. (2010). Bacterial diversity in water injection systems of Brazilian offshore oil platforms, *Applmicrobiol Biotechnol.* 85(3):791–800.
- Korenblum E., Goulart F. R., Rodrigues I.A., Abreu F., Lins U., Alves P. B., Blank A.F., Valoni E., Sebastian G. U. Alviano D. S., Alviano C. S., Seldin L., (2013) Anti-microbial action and anti-corrosion effect against sulphate reducing bacteria by lemongrass (*Cymbopogon citratus*) essential oil and its major components, the citral, *AMB express*, 3: 44, 1-8
- Little B.J., Lee, J.S. (2007). Microbiologically influenced corrosion. Hoboken, New Jersey: Wiley Sons Inc.
- Miranda, E., Bethencourt, M., Botana, F., Cano, M. (2006). Biocorrosion of carbon steel alloys by an hydrogenotrophic sulfate-reducing bacterium *Desulfovibrio Capillatus* isolated from a Mexican oil field separator. *Corrosion Sci.*, 48:2417–31.
- Muyzer G, Stams A.J.M. (2008). The ecology and biotechnology of sulphate-reducing bacteria. *Nat. Rev. Microbiol.* 6:441–454
- Nahle, A., Abu-Abdoun, I., Abdel-Rahman, I. and Al-Khayat, M.( 2010), UAE Neem Extract as a corrosion inhibitor for carbon steel in HCl solution, *International Journal of Corrosion* Hindawi Publishing Corporation, Article ID 460154. 9.
- Nemati M., Jenneman GE, Voordouw G (2001a) Mechanistic study of microbial control of hydrogen sulfide production in oil reservoirs. *Biotechnol Bioeng* 74:424–434
- Nemati M, Jenneman GE, Voordouw G (2001b) Impact of nitrate-mediated microbial control of souring in oil reservoirs on the extent of corrosion. *Biotechnol Progr* 17:852–859.
- Ngobiri N.C, Oguzie E.E, Li Y, Liu L, Oforka N.C, and Akaranta O., (2015), Eco-Friendly Corrosion Inhibition of Pipeline Steel Using *Brassica oleracea*, *International Journal of Corrosion* 10. 1155, 404139
- Nuryastuti T, Van der Mei HC, Busscher HJ, Irvati S, Aman AT, Krom BP (2009). Effect of cinnamon oil on *icaA* expression and biofilm formation by *Staphylococcus epidermidis*. *Appl Environ Microbiol* 75:6850–6855.
- Omokhua G.E., (2011) Medicinal and socio-cultural importance of *Costus afar* in Nigeria, *International Multidisciplinary Journal, Ethiopia*, 5(5): 282-287
- Oyeleke, S.B., Oyewole O.A., Abioye, O.P. (2005). Microbial Influenced corrosion of metals (a review). *Ife Journals of Science*, 7 (1): 21-24.

- Oyewole, O.A. (2011). The Relationship of biofilms and physicochemical properties of soil samples with corrosion of water pipelines in Minna, Niger State, Nigeria. *Continental Journal of Microbiology*, 5(2): 1-10.
- Oyewole, O.A., Oyeleke, S.B., Mohammed, S.S.D., Ibrahim, A. (2011). Microorganisms associated with corrosion of water pipeline in Minna, Niger State, Nigerian *Journal of Technological Research*, 6(2):18-24.
- Oyewole, O. A., Abalaka, M.E., Damisa, D. (2012), Inhibitory Effects Of Nicotine On Corrosion Caused By *Desulphovibrio* Sp. Isolated From Water Pipes in Minna Nigeria *Journal of Science & Multidisciplinary Research*, 1(2): 1-7
- Postgate J.R., (1965). Recent advances in the study of the sulfate-reducing bacteria. *Bacteriol Rev.*, 29:425–441.
- Potgieter. J.H., (2010), Corrosion of Passive Alloys: The Effect of Noble Metal Additions. *Shreir's Corrosion*, 3: 2224-2249.
- Reichling J., Schnitzler P., Suschke U, Saller R (2009), Essential oils of aromatic plants with antibacterial, antifungal, antiviral, and cytotoxic properties—an overview. *Forsch Komplementmed* 16:79–90.
- Rueter, P., Rabus, R., Wilkest, H., Aeckersberg, F., Rainey, F.A., Jannasch, H.W.(1994). Anaerobic oxidation of hydrocarbons in crude oil by new types of sulphate-reducing bacteria. *Nature*, 8:372:455.
- Yuan S., Bin Liang, Yzhao, Pehkonen S.O, (2013) Surface Chemistry and Corrosion Behavior of 304 Stainless Steel in Simulated Sea Water Containing Inorganic Sulphide and Sulphate Reducing Bacteria. *Corr scie* 75, 353-366
- Solórzano-Santos F, Miranda-Novales MG (2012) Essential oils from aromatic herbs as antimicrobial agents, *Curr Opin Biotech* 23:136–141.
- Stentoft, P.M. (1988). Flowering plants in West Africa. Cambridge University Press: London. 130-131.
- Stewart P.S, Costerton J.W, (2001), Antibiotic resistance of bacteria in biofilms. *Lancet* 358:135–138
- Stewart, P. (2002). Mechanisms of antibiotic resistance in bacterial biofilms, *Int. J.Me. Microbiol*, 292:107 –113.
- Videla H.A., ( 2001), Microbially induced corrosion: an updated overview, *Int. Biodeterior. Biodegradation*, 48:176–201.
- Videla H.A (2002), Prevention and control of biocorrosion. *Int Biodeter Biodegr* 49:259–270.

Zuo R., (2007), Biofilms: strategies for metal corrosion inhibition employing microorganisms.  
*Appl Microbiol Biotechnol* 76:1245–1253. doi:10.1007/ s00253-007-1130-6