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EVALUATION OF CORROSION COST OF CRUDE OIL PROCESSING INDUSTRY

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Abstract

Crude oil production industry as the hub of Nigeria Economy is not immune to the global financial meltdown being experienced world over which have resulted in a continual fall of oil price. This has necessitated the need to reduce cost of production. One of the major costs of production is corrosion cost, hence, its evaluation. This research work outlined the basic principles of corrosion prevention, monitoring and inspection and attempted to describe ways in which these measures may be adopted in the context of oil production. A wide range of facilities are used in crude oil production making it difficult to evaluate precisely the extent of corrosion and its cost implication. In this study, cost of corrosion per barrel was determined and the annualized value of corrosion cost was also determined using the principles of engineering economy and results analyzed using descriptive statistics. The results showed that among the corrosion prevention methods identified, the use of chemical treatment gave the highest cost contribution (81%) of the total cost of prevention while coating added 19%. Cleaning pigging and cathodic protection gave no cost. The contribution of corrosion maintenance methods are 60% for repairs and 40% for replacement. Also among the corrosion monitoring and inspection identified, NDT gave the highest cost contribution of 41% of the total cost, followed by coating survey (34%). Cathodic protection survey and crude analysis gives the lowest cost contribution of 19% and 6% respectively. Corrosion control cost per barrel was found to be 77 cent/barrel. The significance of this cost was not much due to high price of crude oil in the international market. But the effect of corrosion in crude oil processing takes its toll on crude oil production (i.e. deferment).

Keywords: Deferment, Downtime, Downhole, Annuities and corrosion control.

Nomenclature

A_v	Annualized value of corrosion control cost, US$
C_{1-11}	Cost of corrosion control methods, US$
F_v	Future value of corrosion control cost, US$
f	Inflation rate
I	Real or inflation free interest rate
I_f	Market interest rate
n	Number of years under study (years)
P_v	Present value of corrosion control cost, US$

1. Introduction

The engineering profession is faced with corrosion problem as most of the materials we make use of are metallic. This problem cuts across all the engineering fields. The activities of corrosion can be seen as nuisance to the engineering profession, as it deprives the industry a huge amount of money. The secret of effective engineering lies in controlling rather than preventing corrosion, because it is impracticable to eliminate corrosion.

To one degree or another, most materials experience some type of interactions with a number of diverse environments in the crude oil production industries. Quite often, such interactions impair the usefulness and reduce the service life of the facilities made up of the materials. The facilities that are mostly affected by corrosion activities include down hole tubing, surface pipelines, pressure vessels, storage tanks and plants which are used to support production operations i.e. pumps and compressors. The expensive and high cost of replacement of crude oil production facilities which are chiefly due to corrosion activities are the factors that make it economically necessary to analyze the cost of corrosion being one of the main cost item in production cost to avoid running the oil industry at loss [1]. The estimated cost of corrosion in the electric power industry in 1998 was $17 billion, representing about 7.9% of the cost of electricity in the United States. About 22% of the corrosion costs were considered avoidable [2]. The whooping sum of $170 billion per year is spent on corrosion in all the United States industries [3].

Although, there are quite a number of texts on corrosion, we have relatively small quantity that specifically take into account, the measure of corrosion in crude oil production industries and in Nigeria corrosion is seen as just a normal process needing limited attention. Corrosion should be given a critical attention in crude oil industry as its cost constitute a major part of production cost and also aids the activities of oil pipeline vandals. Consequences of corrosion in oil production industry could be fatal or severe leading to deferment due to downtime or temporary shutdown of flow station as in the case of western Australian based Exxon Mobil operated offshore in which corrosion problem cause the shutdown of the platform in June, 2002 by the western Australian Department of mineral and petroleum Resources as well as safety of personnel [4]. This of course is as a result of insensitivity to the corrosion activities on the platform. Materials and corrosion control technologies must be improved and evaluated to ensure that they are more reliable to avoid excessive cost of replacement or failure especially in offshore locations loss [1].

One of the major goals of doing business is to make profit. Production costs of oil are not tied directly to commodity (oil) price [5]. The price of oil is regulated by OPEC (Organization of petroleum Exporting countries) as it is responsible for 70% of the world energy requirement. The commodity price of oil and the cost of production will continue to dictate whether or not, production will continue at a profitable rate. The activity of pipeline vandals which is even aided by corrosion has also caused appreciable increases in the cost of production due to frequent repairs or replacement of facilities. Above all, the current downward trend of oil price and the global financial crises has necessitated reduction in the cost of production. Corrosion cost being one of the major cost items in production cost, hence the necessity to evaluate its cost in oil production and the interest is to keep it at the minimum using advanced corrosion prevention and maintenance technologies.

From time to time, it has become customary to attempt to assess the real cost of metallic corrosion. Millions of naira is lost each year because of corrosion. Much of this loss is due to the corrosion of iron and steel, although many other metals may also corrode [6]. The facilities affected by corrosion activities in the oil industry include downhole tubing, surface pipelines, pressure vessels and storage tanks. They are subject to internal corrosion by water, which is promoted by the presence of CO_2 and H_2S in the gas phase. The mechanism of CO_2 corrosion is generally well defined. However, the reality inside a pipeline becomes complicated when CO_2 acts in combination with H_2S, deposited solids and other environments. Solid such as formation sand, can both erode the pipe line internally and cause problems with under-deposit corrosion, if stagnant. Although external corrosion contributes to the corrosion cost, internal corrosion control is the major cost item loss [1]. The objective of this study is therefore to establish an estimate of the cost of corrosion in the crude oil processing industry.

2. Methodology

Corrosion causes, effects, prevention, monitoring, inspection and their relative cost are not theoretically quantified nor practically quantified in door. It involves coming up with reliable data which therefore requires undoubtedly, a lot of field survey. For this research work, OML 124 was used as case study. This is an onshore oil production platform at South-Eastern part of Nigeria. The production platform currently produces about 7500 barrels of oil per day.

Since data were collected from a single organization, the use of questionnaire was not necessary. In some cases, the data is in large volumes and therefore obtained as soft copies. Data was also collected through interview proforma. Data was obtained from the Production Engineer, Production Chemist, Maintenance Engineer and anyone directly involved in carrying out corrosion activities.

Data collected include records of failure, maintenance record, deferment record, asset replacement record, frequency of repair activities and their corresponding cost. Other information obtain include corrosion prevention methods such as coating, chemical treatment, cathodic protection, cleaning, pigging and the corresponding cost. Also information on corrosion monitoring methods such as coating survey, chemical analysis, cathodic protection survey, non destructive test (ultrasonic thickness measurement), intelligent pigging and the cost were obtained. The frequency of use of each method was also ascertained whether it is daily, weekly, monthly, annually or perennially. Finally, the total revenue per year was obtained. Data collected dates back to five years, i.e., 2004-2008). The data obtained was analyzed to evaluate the cost on corrosion prevention, monitoring and inspection and maintenance on annual basis. Furthermore, data was analyzed to evaluate cost incurred on direct corrosion and indirect corrosion effect. Consequently, the percentage of corrosion costs and effect of corrosion cost on the revenue was determined.

3. Method of Data Analysis

The method of data analysis used varied from simple average to the use of percentages. Various statistical methods were also employed in the data analysis. The present and annual worth method of Engineering Economy was used for the corrosion cost evaluation.

The future values of the costs in previous years, i.e., 2004-2007 were calculated in 2008 using the compound amount single payment factor:

$$F_v(2008) = P_v(F_v / P_v, I_f \%, n) = P_v(1 + I_f)^n \tag{1}$$

$$I_f = i + f + (i \times f) \tag{2}$$

The real interest rate and inflation rate from 2004 to 2008 is given in Table 9.

The discounted annual value of the total cost in 2008 was then calculated using the continuous compounding capital recovery factor:

$$A_v = P_v(A_v / P_v, I_f \%, n) = P_v\left(\frac{I_f e^{I_f n}}{e^{I_f n} - 1}\right) \tag{3}$$

Following the notations given to various corrosion prevention methods and the corresponding cost, an evaluation of the corrosion prevention methods is presented in Table 1.

Table 1. Cost Contribution of Corrosion Prevention Methods.

	cost($)				
Year	**C_1**	**C_2**	**C_3**	**C_4**	**Total**
2004	-	59,334	-	-	59,334
2005	9273	53,106	-	-	62,379
2006	45836	63,849	-	-	109,685
2007	32,886	96,037	-	-	128,923
2008		105,783	-	-	105,783
Total	87,995	378,109	-	-	466,104

No real cost is associated with cleaning pigging (P_4) as it is carried out by maintenance personnel in conjunction with the production personnel on the field at no cost. Cathodic protection (P_3) was not installed within the years in view. The percentage cost of corrosion prevention methods is shown in the chart below. The percentage cost contribution of each corrosion prevention method is presented in Fig. 1.

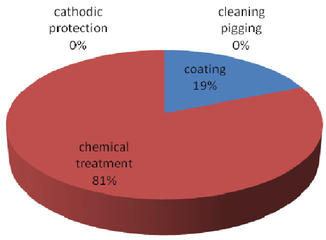

Fig. 1. Percentage Cost of Corrosion Prevention Methods.

Chemical treatment (P_2) basically involves the use of corrosion inhibitors, scale inhibitors and biocides. The frequency and the cost of the chemical treatments within the five years in view are shown in Table 2. The percentage cost contribution of each chemical treatment is presented in Fig. 2.

Table 2. Frequency of Chemical Treatments.

Chemical Treatment	Frequency	cost($)
Scale Inhibitor	Daily	226,561
Corrosion Inhibitor	Daily	56,993
Biocides	Monthly	94,552
Total		378,106

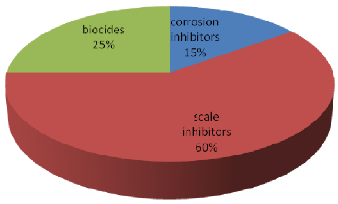

Fig. 2. Percentage Cost Contribution of Chemical Treatments.

Following the notations given to various corrosion maintenance methods and the corresponding cost, the evaluation of the corrosion maintenance methods is presented in Table 3.

Table 3. Cost Contribution of Corrosion Maintenance Methods.

Year	C_5	C_6	Total
2004	16,750	28,900	**45650**
2005	15,580	43,800	**59380**
2006	16,710	29,140	**45850**
2007	21,360	24,560	**45920**
2008	23,260	43,568	**66828**
Total	**93,950**	**169,968**	

Figure 3 shows the percentage cost contribution of each corrosion maintenance method.

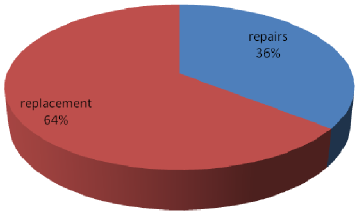

Fig. 3. Percentage Cost Contribution of Maintenance Methods.

Following the notation given to various corrosion monitoring and inspection methods and the corresponding cost, an evaluation of the corrosion monitoring and inspection methods is presented in Table 4.

Table 4. Cost Contribution of Corrosion Monitoring and Inspection Methods.

	cost($)					
Year	C_7	C_8	C_9	C_{10}	C_{11}	**Total**
2004	2225	-	9451	-	-	11676
2005	3210	-	-	-	-	3210
2006	3955	-	-	-	-	3955
2007	4215	108715	-	131285	-	244215
2008	5742	-	49,245	-	-	54,987
Total	19347	108715	58696	131283	-	318,043

The cost of crude analysis involves the cost of chemical used in the analysis. Coating survey is usually carried out once in five years. Also Non destructive test in form of ultrasonic thickness measurement is also usually carried out once in five years. Intelligent pigging which is supposed to be carried out once in five years was not done within the years in view. Also cathodic protection survey which is supposed to be done once in five years on all the facilities was only carried out on the vessels in 2004 and also on the main oil pipeline in 2008. The main oil pipeline is about 47 km long.

The percentage cost contribution of each monitoring and inspection method is presented in Fig. 4.

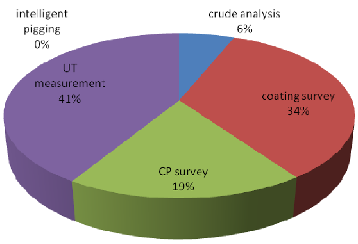

Fig. 4. Percentage Cost Contribution of Monitoring and Inspection Methods.

The cost of deferment due to repair and replacement activities was determined by multiplying the number of barrels deferred with the price of oil at that time. This is shown in Table 5. Most repairs and replacements are done on damaged, leaking or ruptured flow lines due to corrosion. The percentage cost contribution of each corrosion control method to the total cost of corrosion control is presented in Fig. 5. The chronology of crude oil price is also shown in Table 6 [7]. The cost of corrosion control methods is presented Table 7 and Figs. 6 and 7.

Table 5. Production Lost due to Deferment.

Year	Deferment (bbls)	Oil Price/barrel ($)	Deferment cost ($)
2004	592	50	29600
2005	9836	60	590160
2006	480	75	36,000
2007	1292	100	129200
2008	6219	140	867860

Table 6. Chronology of Crude Oil Price [7].

Year	Price/barrel ($)
2004	40
2005	50
2006	60
2007	75
2008	100

Table 7. Total Cost of Corrosion Control.

	cost($)			
Year	**Prevention**	**Maintenance**	**Monitoring and Inspection**	**Total**
2004	59,334	45,650	11,676	116,658
2005	62,379	59,380	3,210	124,969
2006	109,685	45,850	3,955	159,490
2007	128,923	45,920	112,930	287,773
2008	105,783	66,828	68,112	240,723
Total	466,104	263,628	199,883	929,613

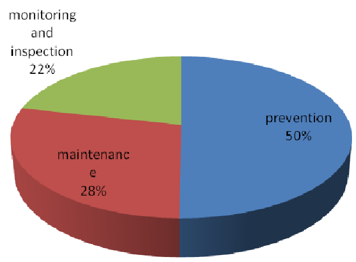

Fig. 5. Percentage Contribution of Corrosion Control Methods.

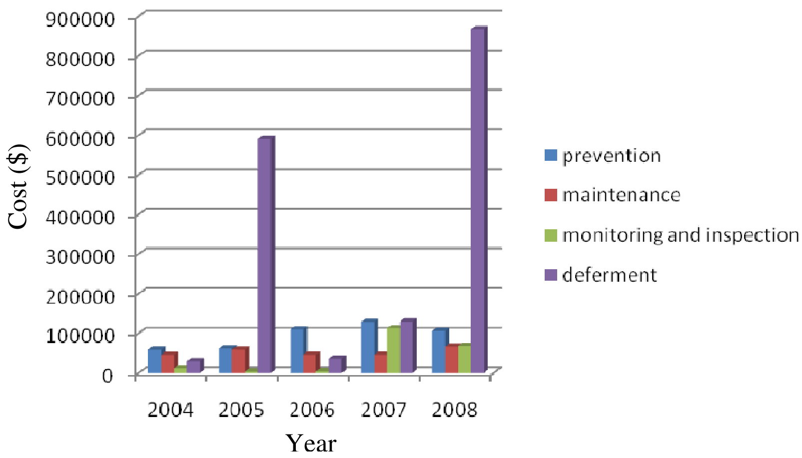

Fig. 6. The Cost of Corrosion Parameters for each Year.

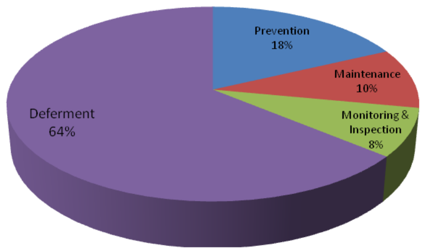

Fig. 7. The Percentage Contribution of Corrosion Cost Parameters.

The total corrosion cost and the price of crude oil per barrel for the years under review are given in Tables 8, 9, and 10.

Table 8. Total Cost of Corrosion Control.

			cost($)		
Year	**Prevention**	**Maintenance**	**Monitoring and Inspection**	**Deferment**	**Total**
2004	59,334	45,650	11,676	29600	146,260
2005	62,379	59,380	3,210	590160	715,129
2006	109,685	45,850	3,955	36000	195,490
2007	128,923	45,920	112,930	129200	416,993
2008	105,783	66,828	68,112	867860	1,108,553
Total	466,104	263,628	199,883	1652820	2,582,425

The market interest rates for the year under review were determined using Eq. (2) and presented in Table 9.

To determine the value of the corrosion cost per year in year 2008, all corrosion control cost each year from 2004 to 2007 are discounted to 2008 (Fig. 8) using Eq.

(1) and the prevalent market interest rate shown in Table 9. Various discounted values in 2008 were now converted to annuities using Eqn. 3 and results shown in Fig. 9 and Table 10 respectively (numerical calculations shown in Appendix *A*). It should be noted that all corrosion control costs are end of year payments.

Table 9. Interest Rate and Inflation Rate Used [7].

Year	Interest Rate (%)	Inflation Rate (%)	Market Interest Rate (%)
2004	17.5	13.8	33.72
2005	15.5	16.5	34.56
2006	12.5	13.5	27.69
2007	9.7	10.5	21.22
2008	10.5	5.4	16.47

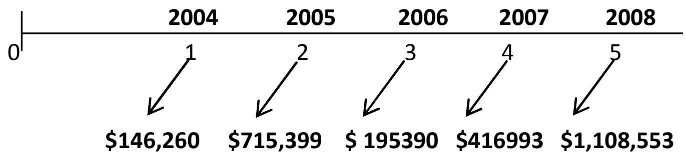

Fig. 8. Cash Flow Diagram for Present Value of Corrosion Cost from 2004-2008.

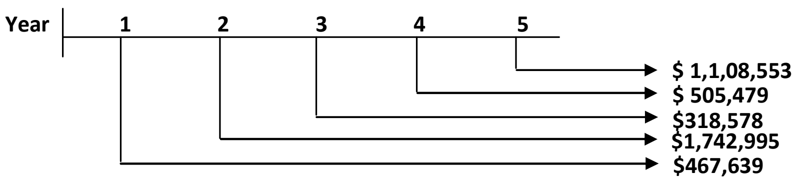

Fig. 9. Cash Flow Diagram for Future Worth Conversion into Annuities at Base Period (2008).

Table 10. Summary of Annual Corrosion Cost.

	Year	Present Value($)	Future value(2008)$ $F_v = P_v (F_v/P_v, I_f\%, n)$	Annual Value($) $A_v = P_v(A_v/P_v, 16.47\%, 5)$
1	2004	146,260	467,639	137,274
2	2005	715,399	1,742,995	511,651
3	2006	195,390	318,578	93,517
4	2007	416,993	505,479	148,382
5	2008	1,108,553	1,108,553	325,412
Total				**1,216,236**

- **Calculation of corrosion cost per barrel**

Average production from 2004 to 2008 is

$$= \frac{1245400 + 1114680 + 1340155 + 2015777 + 2220340}{5} = 1587270 \text{ barrels}$$

Corrosion cost per barrel is $= \frac{1216237}{1587270} = 0.766$ dollar/barrel= 77 cent/barrel

4. Results and Discussion

Among the corrosion prevention methods, coating gave (19%) contribution while chemical treatments gave the highest cost contribution of (81%), others such as cleaning pigging were done at no cost while cathodic protection was not done during the years in view. Chemical treatments as one of the corrosion prevention methods which involve the use of scale inhibitors applied daily gave the highest cost contribution of 59.92% of chemical treatment. This is followed by biocides which is used monthly and gave 25% of the cost of the treatment while corrosion inhibitor gives the lowest cost contribution of about 15.07% and it is also used daily. The use of corrosion inhibitor can be said to be the most cost effective chemical treatment.

Among the corrosion maintenance method, replacement gave the highest cost contribution which is 64.4 % of the cost while repair gave 35.6% of the cost. Among monitoring and inspection method, Non destructive test (ultrasonic thickness measurement) which was done once within the five years in view gave the highest cost contribution of 41.3% of the cost, followed by coating survey which gave 34.2%. It was also done once. This is followed by cathodic protection survey which gave 18.5% of the cost. Crude analysis gives the lowest cost contribution of these methods taking about 6% of the cost and it is used the most (daily). It could be said to be the most cost effective of the methods. Considering the methods of corrosion control, corrosion prevention method gave the highest cost contribution of 50.14%, while corrosion maintenance gives 28.35% of the cost. The monitoring and inspection cost gives the lowest cost contribution of 21.5%.

Evaluating the total cost of corrosion, corrosion prevention cost is 18.05%, corrosion maintenance cost is 10.21%, corrosion monitoring and inspection cost is 7.74% while deferment gave the highest cost (64%). Cost of corrosion per barrel was found to be 77 cent per barrel. This is relatively high compared to a similar study carried out by Gregory and Mohammed [1] in an onshore field in United States in which the corrosion cost was found to be 20 cent per barrel. From the results, it can be seen that deferment cost as one of the forms of indirect corrosion is on the high side. Deferment rubs the industry of huge sum of money as a major indirect corrosion cost. A more effective means of corrosion prevention, monitoring and inspection will reduce deferment and maintenance cost to the minimum.

The other forms of indirect corrosion costs are the staff wages for which data was not provided and environmental problems such as spillage resulting from corroding facilities which give negative public image and increase scrutiny from the regulators for which data was also not provided.

5. Conclusions

From the result, it can be seen that deferment cost as one of the major forms of indirect corrosion is on the high side. Deferment which is most times due to repairs and replacement activities rubs the industry of huge sum of money as a major indirect corrosion cost. A more effective and vigorous means of corrosion prevention, maintenance, monitoring and inspection will reduce deferment and corrosion control cost to the minimum.

In this study, cost of production in an offshore location was not included. Corrosion mitigation cost in this kind of location is more expensive. The effect of corrosion cost was not much due to high price of crude oil at the international market.

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Appendix *A*

Calculations of Corrosion Cost per Year for Period under Study (2004-2008)

For 2004:

$$F_v(2008) = P_v(1+I_f)^n$$

But, $I_f = i + f + (i \times f)$

$i = 0.175, f = 0.138$, therefore

$I_f = 0.3372$, and

$$F_v(2008) = 146260(1+0.3372)^4 = \$467,639$$

The annual value of the spread over five years of study is determined by

$$A_v = P_v\left(A_v / P_v, I_f\,\%, n\right)$$

$$= P_v\left(\frac{I_f e^{I_f n}}{e^{I_f n}-1}\right) = 467639\left(\frac{0.1647\times e^{0.1647\times 5}}{e^{0.1647\times 5}-1}\right) = \$137,274$$

For 2005:

$i = 0.165, f = 0.155$

$I_f = 0.155+0.165+ (0.155 \times 0.165) = 0.3456$

$F_v\ (2008) = 715399 \times (1 + 0.3456)^3 = \$1,742,995$

$$A_v = 1742995\left(\frac{0.1647\times e^{0.1647\times 5}}{e^{0.1647\times 5}-1}\right) = \$511,651$$

For 2006:

$I_f = 0.125 + 0.135 + (0.125 \times 0.135) = 0.2769$

$F_v\ (2008) = 195390\times(1 + 0.2769)^2 = \$318,578$

$$A_v = 318578\left(\frac{0.1647\times e^{0.1647\times 5}}{e^{0.1647\times 5}-1}\right) = \$93,517$$

For 2007:

$i = 0.097, f = 0.105$

$I_f = 0.097 + 0.105 + (0.097 \times 0.105) = 0.2122$

$F_v\ (2008) = 416993\times(1 + 0.2122)^2 = \$505479$

$$A_v = 505479\left(\frac{0.1647\times e^{0.1647\times 5}}{e^{0.1647\times 5}-1}\right) = \$148,382$$

For 2008:

$i = 0.105, f = 0.054$

$I_f = 0.105 + 0.054 + (0.105 \times 0.054) = 0.1647$

$$A_v = 1108553\left(\frac{0.1647\times e^{0.1647\times 5}}{e^{0.1647\times 5}-1}\right) = \$325,412$$

Therefore, total annualized value over the five years is

Total = $(137,274 + 511,651 + 93,517 + 148,382 + 325,412)

= **$1,216,236**