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Research Paper

Investigation of Corrosion Induced Degradation in Oil Pipelines

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ABSTRACT

Corrosion has been identified as a major concern in the oil and gas industry. To this end, the study investigated the corrosion induced degradation in oil pipelines within the South-South geo-political region of Nigeria. To achieve this, Direct Field Assessment Method (DFAM) was used to obtain field data because it helps ascertain which corrosion type prevails in the selected regions, since pipelines are susceptible to various kinds of corrosion depending on the potential difference between the pipe and the ground surface within a corrosive environment. The reliability and the failure rate of these pipelines in the Niger Delta regions due to corrosion were determined. Results reveal that 70.83% of the pipeline corrosion that occurs in the South-South geo-political region of Nigeria from 1999 – 2015 is due to Stress Corrosion Cracking (SCC) and that there is a seemingly correlation between the 3rd party activity (vandalism) and corrosion. This is because the areas with higher 3rd party activity have corresponding higher failure rate and corrosion occurrence. However, despite the effect of 3rd party activities and corrosion activities, the reliability result suggests that the oil pipelines are still within their useful life stage.

Keywords: Corrosion, Pipelines, Failure, Reliability, Degradation.

INTRODUCTION

Pipelines serve veritable purposes in the oil and gas industry as they are the main medium for the transportation of crude oil and products of refined crude oil. A pipeline system is said to be suitable for transportation of large quantities of oil and gas because there is relative freedom from impacts of weather conditions. Furthermore, it affords promising opportunities, for labour saving and automation and is also one of the safest and most reliable means of transportation. The integrity of pipeline systems used for the transportation of crude oil and petroleum products must be sound in order to ensure risk free. Most metals occur naturally as stable oxides and since pipelines are basically made of metals and its alloys, metals that has been processed into steel tends to return to that stable state via oxidation when it reacts with its environment in the presence of moisture no matter how small. This process is termed corrosion. Corrosion has been adjudged a cause of concern in the Nigerian oil and gas industry space. [1] reported a total of 137 pipeline failures across six states in the Niger Delta region of Nigeria in the period 1999-2005, and corrosion accounted for 18% of these failures. This finding underscores the importance of researching into this prevailing challenge. Revenues from the crude oil make up the main stream of the national economy. Major transportation mediums for this crude oil are pipelines. These pipelines cover thousands of kilometres in their bid to transport oil in both its crude and refined form across various locations. Most transmission pipelines are buried underground to

minimize their contact with external influences. The soils usually contain deleterious chemicals and microbes that accelerate the deterioration of the pipe steel through corrosion. This makes corrosion one of the leading in-service defects resulting in pipeline failures, and hence stressing the need to investigate the mechanism of corrosion induced degradation in these oil pipelines. The study aims to investigate the degradation of oil pipelines induced by corrosion with the following as its set objectives:

- To identify the prevailing corrosion type(s) pipelines in the South-South geo-political area of Nigeria are susceptible to.
- To carry out an age and performance rating in order to determine the failure rate and reliability of these pipelines as a result of corrosion.
- To proffer solutions to mitigate the effect of corrosion on the oil pipelines.

Owing to the attendant consequences of corrosion on the pipelines, running cost, and eventually the ecosystem, this study will bring to the front burner, the mechanism of corrosion in oil pipeline, ways to protect in service pipeline in order to greatly reduce their failure rate and optimize their operations. Results of the study will also be a useful tool in the proposed Ajaokuta–Kaduna–Kano (AKK) gas pipeline project. While on the international scene, outcome of the study will be helpful in the proposed gas pipeline, to be built through a partnership between the NNPC and Algeria's which would, stretch 1,037 kilometres from Nigeria to the Niger border, 841 kilometres from Niger to Algeria, 2,303 kilometres across Algeria and 220 kilometres from Algeria to Spain and would have an estimated annual capacity of 30 billion cubic litres of natural gas. It is expected to be operational from 2020.

METHODOLOGY

Data Collection: Investigation into the degradation of oil pipeline in other to ascertain which corrosion type(s) prevails in the Niger Delta regions of Nigeria was carried out using results from Direct Field Assessment Method (DFAM). The choice of this method was informed by the related researches where it was established that pipelines are susceptible to various kinds of corrosion depending on the potential difference between the pipe and the ground surface within a corrosive environment. [2] DFAM utilizes a $Cu/CuSO_4$ electrode, a test probe, and a voltmeter in determining the potential difference between the buried pipe and the ground surface. The electrode and probe are connected to the voltmeter while the other ends of the electrode and probe are connected to the ground surface and the pipeline surface respectively.

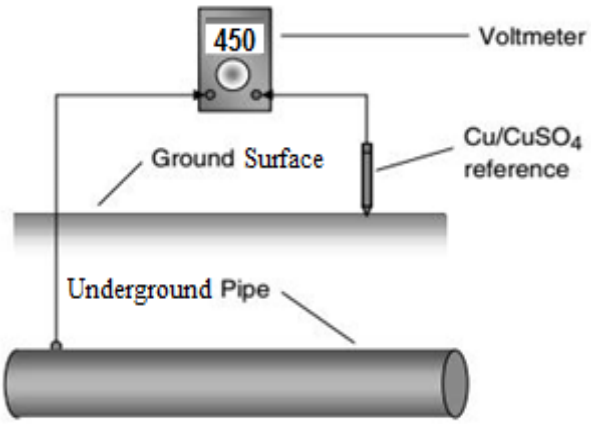

Figure 1: DFAM measurement. [3]

In alkaline environment, SCC occurs in relatively narrow range of potentials, approximately from -650 to -750 mV $Cu/CuSO_4$. On the contrary, in acidic to neutral environment with pH = 5.5 to 7, SCC occurs in the interval of potentials from -760 to -790 mV $Cu/CuSO_4$. [4]

Reliability and Failure Rate Determination: The reliability and the failure rate of these pipelines in the Niger Delta regions due to corrosion were carried out by adopting the methodology used by [1] where data was collected from known periodicals and other literature, as well as the databases of Nigerian National Petroleum Corporation (NNPC), Department of Petroleum Resources (DPR), Shell Petroleum Development Company

(SPDC) and other secondary sources that are responsible for operating oil and gas pipelines in the Niger Delta Area of Nigeria. The data collected included the following:

- Pipeline network data of the major crude oil and product trunk transportation pipelines, including feeder lines and local gathering systems (where applicable) in the States of Niger Delta area of Nigeria.
- Pipeline failure data during the period 1999-2015 from the pipelines. Types of data collected included: date of event, site specification (that is, pipeline identification and geographical location), spill quantity and duration, causes and consequences, clean up and restoration, etc.
- Geographical and environmental data to identify important environmental factors, as well as populations, habitats, or other environmental features of each state of Niger Delta area along the pipelines that are vulnerable to oil spills.
- Oil spill contingency plan data including existing contingency plans, type of clean up equipment, capacities, and so forth in the region.

RESULTS AND DISCUSSION

Result of the Direct Field Assessment Method (DFAM): Result of the DFAM carried out on the major oil pipelines located in the south-south geopolitical areas of Nigeria is recorded in Table 1.

Table 1: DFAM result.

	Akwa-Ibom			Bayelsa			Cross River			Delta			Edo			Rivers		
Diameter Class (mm)	pH	V	Corr. Type	pH	V	Corr. Type	pH	V	Corr. Type	pH	V	Corr. Type	pH	V	Corr. Type	pH	V	Corr. Type
203 – 355	6.4	-810	MIC	5.7	-762	SCC	6.1	-785	SCC	5.8	-784	SCC	7.1	-777	SCC	5.5	-783	SCC
381 – 558	6.3	-805	MIC	5.8	-772	SCC	5.9	-804	MIC	5.5	-790	SCC	6.7	-769	SCC	5.4	-763	SCC
609 - 812	6.7	-794	MIC	5.5	-782	SCC	6.0	-795	MIC	5.6	-781	SCC	6.1	-783	SCC	5.6	-785	SCC
> 812	7.1	-802	MIC	5.8	-774	SCC	6.7	-798	MIC	5.6	-789	SCC	5.8	-771	SCC	5.4	-765	SCC

V = Voltmeter reading in mV

The table revealed that 70.83% of the pipeline corrosion that occurs in the Niger Delta regions of Nigeria is due to SCC. As opined by [5] SCC occurs under three conditions, these are: Tensile stress, a susceptible alloy, and a humid environment. These conditions are met in underground oil pipelines because there is a potent environment developing at the pipe surface, susceptible pipe material, and tensile stress. Apart from the stresses exerted on the pipe internal and external surfaces (by the Hoope stress due to the oil passing through the pipe and the compressive stress due to the ground surface above), third party activities such as pipeline vandalism induces far greater stresses on the pipeline leading to propagation of cracks. Table 2 gives information on the oil pipeline failures by state and causes of spill. It also showed why states such as Akwa-Ibom and Cross River are less susceptible to this occurrence. The pH level of soils ranging between 5.9 and 7.1 in the tested area along the oil pipes laid in Akwa-Ibom and Cross River states provides a favourable environment for the breeding of microbes. These microbes are the main culprits for the corrosion experienced in the oil pipelines. [6]

Table 2: Number of oil pipeline failures by state and causes of spill, NNPC, 1999 –2015.

State	Mech. Failure	Corrosion	Operation Error	3rd Party	Natural disaster	Unknown	Total Location	by
Akwa-Ibom	3	4	1	-	-	8	15	
Bayelsa	8	12	4	21	1	25	66	
Cross River	2	1	-		-	4	7	
Delta	5	8	4	11	1	5	33	
Edo	1	5	3	8	-	5	21	
Rivers	6	10	7	18	1	17	59	
Total	25	40	19	58	3	44	202	

From the table above, there is a seemingly correlation between the 3rd party activity and corrosion. 3rd party activities refer to the illegal bunkering on pipelines. The areas with higher 3rd party activity have corresponding higher corrosion occurrence. This suggests that the third party activities initiate stress that propagates cracks throughout the region. With the prevalence of the two already existing condition needed for SCC to occur, areas with higher 3rd party activities are more prone to SCC. This phenomenon is the reason 70.83% of the corrosion incidences are SCC. Table 2 also shows that the main cause of oil spillage in the Niger Delta areas of Nigeria is due to 3rd party activities.

Reliability and Failure Rate Result: The reliability of the pipeline in the Niger Delta region of Nigeria was evaluated using equation 1

$$P_{(t)} = e^{-t/MTBF} \quad (1)$$

Where: t = Operational time (hrs), MTBF = Mean Time Between Failure (km-hr/failure), $P_{(t)}$ = Pipeline Reliability.

The Mean Time Between Failure is determined using the expression in equation 2.

$$MBTF = \frac{lT}{\lambda} \quad (2)$$

Where: *MBTF* = Mean Time Between Failure, λ Failure= rate (km-failure/hr),

L = Length of oil pipeline.

Equation 3 was used to determine the failure rate of the oil pipeline across theNiger Delta region of the country.

$$\lambda = \frac{LN}{t} \quad (3)$$

N = Number of failure

The number of pipeline kilometres by diameter in the Niger Delta states of Nigeria is represented in table 3.

Table 3: Data of pipeline kilometres by diameter in the Niger Delta states of Nigeria.

Diameter (mm)	Akwa-Ibom	Bayelsa	Cross River	Delta	Edo	Rivers	Total (km)
152		28		48		48	104
228				148			148
304				14		48	168
381	136			165			301
457		197		169		60	396
533	24			52	197	356	629
609						274	274
685		742		670			1412
762	183			28	742	1483	2436
838		2874	753	197		398	4222
914	403			1567		958	2928
990		456		342			798
1066		81		43	456	2597	3117
1143		161		897	81		1139
1219	501	197		1231	161	1929	4019
Total (km)	1247	4539	753	5471	1367	8251	21528

(Source: Department of Petroleum Resources (DPR), Shell petroleum Development Company (SPDC), Port-Harcourt, 2010).

The result of the failure rate and reliability of the oil pipelines within the NigerDelta states is presented in Table 4

Table 4: Failure rate, MTBF, and Reliability result for oil pipelines in the Niger Delta States of Nigeria from 1999 to 2015.

State	Oil pipeline distance (km)	Number of failure Recorded	λ (km-failure/hr)	MTBF (km.hr/failure)	Reliability
Akwa-Ibom	1247	15	0.133	11651968	98.8%
Bayelsa	4539	66	2.137	9639185.5	98.5%
Cross River	753	7	0.03	15077211.4	99%
Delta	5471	33	1.29	23236829.1	99.3%
Edo	1367	21	0.20	9123748.6	98.4%
Rivers	8251	59	3.47	19601019.7	99.2%

From Table 4, it can be seen that states with higher failure rates are those states with a record of third party activities. However, despite the effect of 3rd party activities and corrosion activities, it can be concluded that the oil pipelines are still within their useful life stage. This assertion is due to the high reliability values recorded across the states.

CONCLUSION

The study focused on investigating the oil pipeline degradation due to corrosion in the South-South geo-political areas of Nigeria. DFAM was adopted in order to ascertain which corrosion type(s) prevails in the selected regions, since pipelines are susceptible to various kinds of corrosion depending on the potential difference between the pipe and the ground surface within a corrosive environment. The following conclusions are drawn from the findings.

- 70.83% of the pipeline corrosion that occurs in the South-South geo-political region of Nigeria from 1999 – 2015 is due to SCC.
- There is a seemingly correlation between the 3rd party activity and corrosion.
- The areas with higher 3rd party activity have corresponding higher corrosion occurrence. This suggests that the third party activities initiate stress that propagates cracks throughout the region. With the prevalence of the two existing condition needed for SCC to occur (humid environment and susceptible alloy), areas with higher 3rd party activities are more prone to SCC.
- States with higher failure rates are those states with a record of third party activities.
- Despite the effect of 3rd party activities and corrosion activities, it can be concluded that the oil pipelines are still within their useful life stage.

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