

Analysis of Oil Pipeline Failures in the Oil and Gas Industries in the Niger Delta Area of Nigeria

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Abstract - This research work on the analysis of oil pipeline failures in oil and gas industries in the Niger delta area of Nigeria was carried out to ascertain the causes of these failures. Information on pipeline conditions was gathered for the period between 1999 and 2010. Observations showed that the major causes of failure include: Ageing, Corrosion, Mechanical failures – welding defects, pressure surge problems, stress, wall thickness, etc. From the data got and results that were obtained, recommendations were given on measures to minimize these failures. According to the Gas and Oil Pipeline Standards (GOST) of Nigeria, the standard lifetime of a pipeline is 33 years but this research findings revealed that 42% of failures were mechanically induced, 18% by corrosion, third party activity contributed 24%, 10% through operational error and 6% by natural hazards. Besides applying good cathodic protection, or anti-corrosive agents, reinforced thermoplastic pipe (RTP) seems to be the best remedy, as it is able to withstand many factors that lead to failures. The use of RTPs is therefore recommended as a good measure against pipeline failures in the Oil and Gas Industries in Nigeria.

Index Terms - Cathodic protection, Corrosion, Mechanical failure, Niger Delta, Reinforced thermoplastic pipe.

I. INTRODUCTION

MAJOR pipelines across the world transport large quantities of crude oil, natural gas, and petroleum products. These pipelines play an important role in modern societies and are crucial in providing needed fuels for sustaining vital functions such as power generation, heating supply, and transportation. In light of the hazardous properties of the products being transmitted through these pipelines, a ruptured pipeline has the potential to do serious environmental damage. This problem is further compounded by the fact that many developing countries have not established proper guidelines and standards for the design, construction, and operation of major oil pipelines. This study concerns the analysis of oil pipeline failures in the Niger delta area of Nigeria with the aim to undertake a desk study to evaluate the procedures for pipeline maintenance and contingency plans for addressing oil pipeline failures in the Niger delta area of Nigeria. The risk associated with pipeline in terms of safety of people, damage to the environment and loss of income has been a major concern to pipeline integrity managers.

Sources of failure include Structural problem 40%, Operator error 6%, Others 25%, Outside force damage 27% and lastly Control problems 2%. Agbaeze [1]

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shared his view on how to improve pipeline Integrity Management, opining that Pipeline operators can realize many benefits by implementing a data integration approach that; enables integrity managers, risk assessment specialists and pigging Engineers to view and analyze combined information from disparate surveys and to increase the value of data by shaving it across the entire corporation. There have been a number of studies conducted by researchers on causes of oil pipeline failures in the oil and gas industry.

Ikporukpo [2] examined the causes of pipeline leaks versus pipeline ruptures and the proportion for each. In failures resulting in product loss, leaks constituted 86.8% of failures and ruptures 13.2%. Corrosion is the predominant cause of leaks. According to the findings, third party damage is the leading cause of line ruptures. Since 1994, 191 hits were recorded, and these are not included on the graph as they did not result in either leaks or ruptures. The hits equalled 47% of all recorded third-party incidents for the years 1994-1997, demonstrating that approximately half of all third party incidents resulted in a pipeline failure. Reference [3] showed that about 50% of third-party incidents resulted in loss of pipeline products. Ndifon [4] reviewed the number of internal corrosion failures for multiphase pipelines and discovered that internal corrosion failures increased steadily while the number of external corrosion failures held steady. However, the failure frequency has been quite consistent [5], [6].

Moffat and Linden [7] compiled background research and information that is associated with oil pipeline failures, it shows that for crude oil pipelines, the causes of failures appeared to be fairly random in nature, and that no trends were apparent. They stated for sour gas pipelines, internal corrosion is the major cause of failure. External corrosion failures have declined in recent years, possibly as the result of improved coatings and increased inspection. Of the sour line failures, about 86% were leaks and 14% were ruptures. They used the latest technology in the fields of internal electronic inspection, metallurgy, coatings, cathodic protection, and chemical inhibition.

Nwankwo et al [8] and Odusola [9] extensively studied the effects of internal corrosion failures for natural gas pipelines which have generally been increasing. Some "other" category which include high vapour pressure liquids, low vapour pressure liquids, fuel gas, and all others showed failure rates to be relatively few and the causes to be relatively random.

II. MATERIALS AND METHODS

The aim of this study is to rank the oil pipeline incident from data collected from oil and gas industry, so that

pipeline managers can prioritize their strategies for managing the risk involved.

The objectives of the study have been categorized into the following different areas of activities:

- Study the historical oil pipeline failures.
- Assess oil pipeline rupture risks and recommend measures to reduce oil spill probability and impact severity.
- Identify the best practices in developed countries and recommend ways of translating them to areas having inadequate arrangements or combating oil pipeline failures and mitigation of their effects.
- Promote establishment of regulatory and monitoring systems.
- Promote the development of incentive systems to encourage the oil industry to minimize environmental degradation arising from oil pipeline spills (in particular).

In order to fulfil the study objectives, a number of work tasks were identified, comprising:

- Collection of data on pipeline network of Shell Petroleum Development Company (SPDC) in the Niger Delta Area of Nigeria;
- Analysis and risk assessment of the causes of oil pipeline failures in the Niger Delta Area of Nigeria;
- Review of the legal and regulating regimes of Shell Petroleum Development Company (SPDC) pipelines in the Niger Delta Area of Nigeria; and
- Recommendations for strengthening the regulatory and monitoring systems in the Nigerian oil and gas industry.

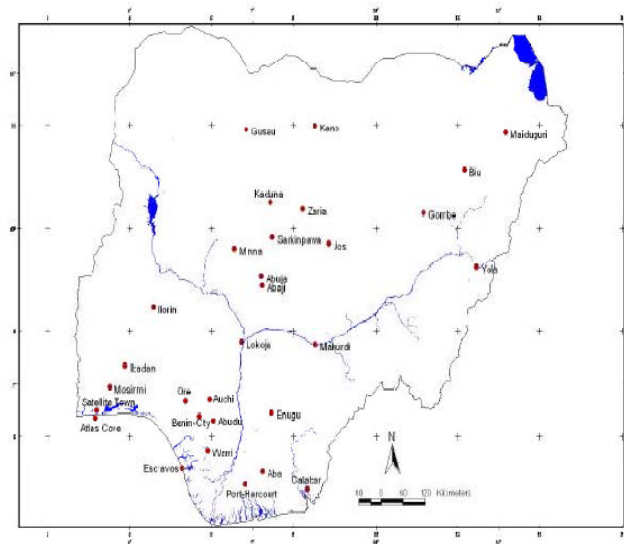


Fig. 1. Nigeria showing Niger Delta, major cities & 5 Operational Zones; Source: Anifowose (2006)

The Niger Delta (Fig.1) is located in Southern Nigeria and is world's third largest wetland. It is characterized by significant biological diversity and contains the bulk of Nigeria's proven oil and gas reserves. The region has about 606 oilfields with 355 situated onshore and 251 offshore (Fig.2). There are about 5,284 oil wells drilled and 527

flow stations for crude oil processing, with more than 7,000 km of oil and gas pipelines traversing the entire area and seven export terminals.

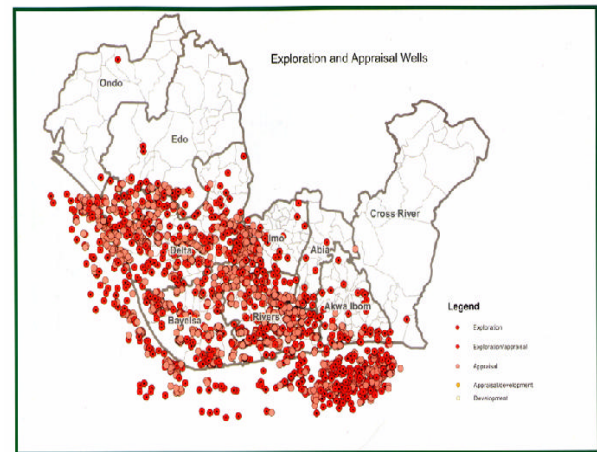


Fig. 2. Niger Delta Showing the Distribution of Onshore and Offshore Oil Fields; Source: NDRDMP (2006)

The land area within which the network of transport pipelines are located is estimated at 31,000km². There are ten gas plants and about 30 marginal oil fields farmed out, through the network of pipelines, to local companies and for export. Three of Nigeria's four refineries, Port-Harcourt I & II and Warri, are located in the region, while the fourth is located in Kaduna, Northern Nigeria.

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 1999-2005 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, cleanup 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 cleanup equipment, capacities, and so forth in the given countries.

Most of the pipeline data were accessed from a digital map of main oil pipelines. The data included location of pipelines, diameter in millimeters, and length in kilometers. The data have been categorized on a state-by-state basis and are summarized in Table 1 below.

There were approximately 84,000kilometers of pipeline in Nigeria as of 1998. About 90% of this pipeline has a diameter of greater than 504mm (20inches) while about 64,000 pipeline kilometers, or 76% of the total, are

located in the Niger Delta States. The distribution of these pipelines in the Niger Delta area of Nigeria is shown in Table 1.

Unlike other countries, the main pipelines in the Nigerian Niger Delta states are combined into unified systems that transport natural gas, oil and petroleum fuels to both domestic and international end users, Natural gas is transported exclusively by the Nigerian National petroleum Corporation (NNPC); oil is transported by a combination of multinational oil companies and the national pipeline operator; and refined petroleum fuels are taken care of by independent oil marketers.

TABLE 1
NUMBER OF PIPELINE KILOMETERS BY DIAMETER IN THE NIGER DELTA STATES

Diameter (mm)	Akwa-Ibom	Bayelsa	Cross-River	Delta	Edo	Rivers	Total
152		28	-	48	-	48	104
228	-	-	-	148	-	-	148
304	-	-	-	14	-	148	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	1247	4539	753	5471	1367	8251	21528

- = Not available

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

The specific age of some of the pipelines are not known, and it was possible to make an objective correlation between the age of pipelines and their rate of rupture [10]. However, a large number of the oil pipelines in the Niger Delta area were put into operation in the 1960s and 1970's (see Table 2 below). As at the year 2000, pipelines older than 20 years constituted 73% of all pipelines while those over 30 years old accounted for 41% of the total network length. Reliability rating for pipelines less than 20 years in service was found to be about 46% while those above 30 years was about 25%. This shows a decline of about 21% and an overall declining pattern with ageing.

TABLE 2
AGE AND PERFORMANCE RATING OF NIGERIAN MAIN OIL PIPELINES AS AT THE YEAR 2000

Age (years)	Year 2000	
	% reliability	% total network length
<20	46	27
20-30	29	32
>30	25	41

(Source: Pipeline Oil Spill Prevention and Remediation in NDS, NNPC, 2007)

The main sources of information for oil pipeline failures cited in this study are the following:

- Database of the Oil Spill Intelligence Report (NNPC), Port Harcourt.
- Shell Nigeria Annual Reports, Port Harcourt, Nigeria.
- Hazardous Cargo Bulletin (HCB), NNPC, Nigeria.
- Oil and Gas Journal (OGJ), Lagos, Nigeria.
- Major Hazard Incident Data Service Database (MHIDAS); Health and Safety Executive (owner), AEA Technology (operator), Lagos, Nigeria.
- Institution of Chemical Engineers Accident Database (I.Chem. E), Port Harcourt, Nigeria.
- Ministry of Niger Delta Area, Abuja, Nigeria.

Note: Ministry of Niger Delta Area covers developmental projects in the Oil producing states.

The relevant data on each of the oil pipeline failures are summarized in Tables 3-5 below. The causes of spills were analyzed in accordance with the internationally accepted nomenclature (NNPC 1997)

TABLE 3
A SUMMARY OF THE VARIOUS CAUSES OF OIL PIPELINE FAILURE IN THE NIGER DELTA REGION OF NIGERIA

Mechanical Failure	Corrosion	Operational Failure	Third-party Activity	Natural Hazard
Construction, Material and Structural	Internal, External	System, Human	Accidental, Malicious (Sabotage), Incidental and Acts of Vandalism	Subsidence, Flooding and Others

(Source: Pipeline Oil Spill Prevention and Remediation in NDA, NNPC, 2007)

TABLE 4
NUMBER OF OIL PIPELINE FAILURES BY LOCATION (STATE) AND CAUSE OF SPILL, NNPC, 1999-2005

Location	Cause of spill						Total by location
	Mechanical Failure	Corrosion	Operational error	Third party activity	Natural Hazard	Unknown	
Akwa-Ibom	2	3	1	-	-	6	12
Bayelsa	8	7	4	9	1	18	47
Cross-River	1	-	-	-	-	3	4
Delta	5	4	3	7	1	3	23
Edo	1	2	2	4	-	3	12
Rivers	6	5	7	8	1	10	37
Total by cause	23	21	17	28	3	43	137

- =Not available

(Source: Pipeline Oil Spill Prevention and Remediation in NDS, NNPC, 2007)

TABLE 5
NUMBER OF OIL SPILL ACCIDENTS BY LOCATION (STATE) AND DIAMETER CLASS, NDS 1999-2005

Location	Diameter class(mm)					Total by location
	203 to 355	381 to 558	609 to 812	>812	Unknown	
Akwa-Ibom	-	3	1	1	1	6
Bayelsa	-	14	13	11	1	39
Cross-River	3	5	1	2	1	12
Delta	2	4	6	1	2	15
Edo	-	-	1	10	1	12
Rivers	6	8	10	5	4	33
Total by class	11	34	32	30	10	117

- =Not available

(Source: Pipeline Oil Spill Prevention and Remediation in NDS, NNPC, 2007)

III. RESULTS AND ANALYSIS

Assessment of results generated in this study of pipeline failures, including risk assessment of the environment from oil pipeline spills, was analyzed on a state-by-state basis of the Niger Delta States (NDS). The analysis was performed on data collected for the 113 NDS pipeline spills used in this study that occurred between 1999 and 2005.

Table 5 and Fig. 3 present the number of spills, spill frequency expressed as kilometer-years, and the failure rate for each ND State. Except for Bayelsa, Delta and Rivers, the number of oil pipeline failures is limited. For

Akwa-Ibom, Cross-River, and Edo few pipeline failures were reported. The spill frequencies for these states are represented by lightly colored bars in Fig. 3, because these frequencies are based on a statistical estimate of 0.7 failures (50 percent confidence in Poisson distribution for zero events).

Rivers state has a high pipeline failure rate. This high rate could be due to good reporting of oil spills. One oil spill in Rivers state was definitely identified as sabotage. The ages of Rivers state's pipelines are unknown, but as Rivers state is a mature oil-producing state, a reasonable assumption is that the pipelines are older than average.

The pipeline failure rate in Akwa-Ibom is low. This could be due to poor reporting of oil spills, newer pipelines, better quality of materials used, better maintenance, or less corrosive soil. As stated before, this could be due to teething troubles for new pipelines or wear-and-tear on old pipelines. The age of the pipelines in Akwa-Ibom is not known and so it is difficult to speculate if they are either new or old.

TABLE 6
FAILURE RATES FOR NIGER DELTA STATES, 1999-2005

Location by State	No. of oil Spills	Kilometer-years	Failure rate per 1,000km-years
Akwa-Ibom	12	3,115	0.19
Bayelsa	39	5,222	0.20
Cross-River	3	756	0.14
Delta	41	6,328	0.22
Edo	5	890	0.16
Rivers	46	7,490	0.23
Total	146	23,801	1.14

(Source: Pipeline Oil Spill Prevention and Remediation in NDS, NNPC, 1997)

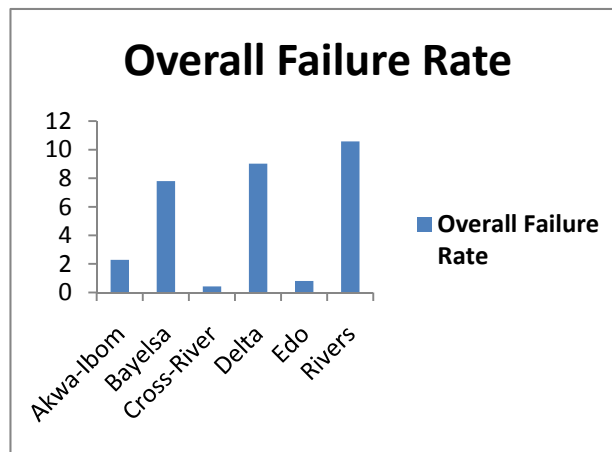


Fig. 3. Variation of Failure Rate by NDSs for All Oil Pipeline Spills, 1999-2005; (Source: Pipeline Oil Spill Prevention and Remediation in NDS, NNPC, 2007)

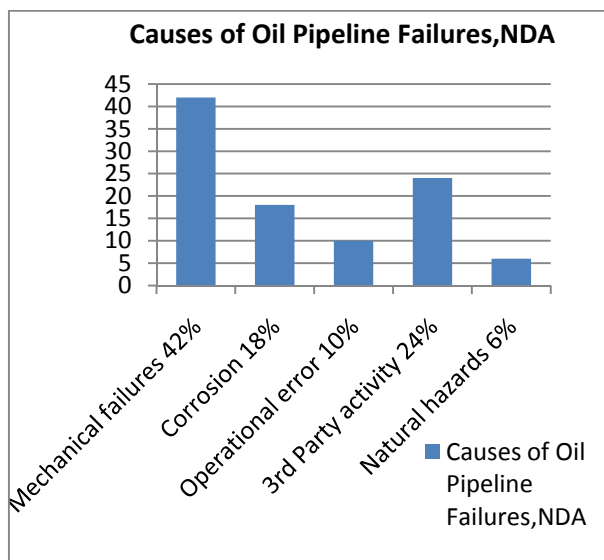


Fig. 4. Distribution of Causes of Oil Pipeline Failures in the NDS, 1999-2005 (Source: Pipeline Oil Spill Prevention and Remediation in NDS, NNPC, 2007)

IV. CONCLUSION

The following are the main conclusions of this study:

(a) Comparing the six states (Akwa-Ibom, Bayelsa, Cross-river, Delta, Edo, and Rivers) of the Niger Delta area as used in this report, Rivers, Delta and Bayelsa, which are the main hub of oil and gas exploration in Nigeria, have higher pipeline failure rates (at 0.6, 0.5 and 0.45 per 1,000 km-years respectively) as compared to Akwa-Ibom, Edo and Cross-river states with pipeline rupture rate of about 0.25, 0.2 and 0.15 per 1,000 km-years, highlighting the fact that the pipelines in Rivers, Delta and Bayelsa states are more susceptible to rupture than in the other Niger Delta states.

(b) The specific ages of the pipelines in which the failures occurred were not available, and hence, it was not possible to clearly establish the statistical significance of this parameter as a cause of pipeline failure. The failure rate of pipelines usually follows a bathtub curve. At the start and the end of the lifetime, failure rates are high; in the middle of the lifetime failure rates are usually low. This could be due to "teething" troubles for new pipelines and due to wear-and-tear as the pipeline gets old.

(c) The severity of spillage, measured by the amount of oil spilled, is higher in the Niger Delta than in Western Europe. The reason could be poor contingency planning for rapid response to spills; poor detection procedures; long distances between emergency shutdown valves; or the larger average diameter of pipelines.

(d) Prevention of failures caused by equipment malfunction is a matter of choosing the right equipment and of proper maintenance and appropriate testing of the particular equipment. Hydrostatic testing by which the pipeline is subjected to pressure above the operating pressure, to blow out defects before they reach a critical size in service is also used to detect corroded pipe before it fails in service.

V. RECOMMENDATIONS

(a) Among the NDs, Rivers state, with 0.8% of total pipeline kilometers had the highest pipeline failure rate during the period of the analysis. Akwa-Ibom and Cross-river states had the lowest failure rates, with 3.4% and 9.8% of total pipeline kilometers respectively. These variations could be due to a number of factors, including the following: Differences in the ages of pipelines; Differences in environmental, climatic, geological, and soil conditions and their effects on pipelines and pipeline routing; Differences in construction standards; Differences in implementation of contingency plans; and Differences in reporting thresholds for oil spill events.

These factors should be reviewed in greater detail so as to establish more precisely the parameters that would explain the differences in failure rate.

(b) Failures due to third-party activities are significant in both the NDs and Western Europe, thereby highlighting the need for establishing an effective regulatory and monitoring mechanism for oil pipeline operation in the country.

(c) External corrosion can be tackled by improved coatings and cathodic protection e.g. use of polyethylene and multilayer coatings have longer life. Early detection of coating degradation is an important strategy and pipes should be subjected to hydrostatic testing [11].

(d) Internal corrosion can be prevented by dehydration of gases and periodic pigging of lines to remove accumulated water and deposits.

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