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Research Paper

ASSESSING PIPELINE INTEGRITY USING SINGLE RUN IN-LINE INSPECTION DATA

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Data from a Magnetic Flux Leakage In-Line Inspection of a 24" x 47 km carbon steel pipeline carrying crude oil in the Niger Delta, Nigeria were analyzed to determine current integrity of the pipeline relative to its operational regime. The pipeline has been in active operation for 14 years before the inspection. Although over 500,000 metal loss features were recorded, less than 0.01% was assessed to be significant. Integrity of the pipeline is therefore rated high. 'Water carry over' into the pipeline and 'water separation' in the pipeline during transmission are adduced to be the major causes of the metal loss observed. Efficiency of processing the product (how dehydrated or de-aerated the oil and gas is respectively) and how constant the transmission velocity and pressure are maintained throughout the pipeline are found to be, more than other factors, the determinants of the rate of deterioration of a pipeline actively carrying fluids.

Keywords: Magnetic flux leakage, In-Line Inspection, Metal loss features, Water carry over, Water separation, Transmission velocity

INTRODUCTION

Nigeria broke into the commity of oil producing nations in 1956 when exploration effort of over 40 years yielded dividend with a commercial find in Oloibiri (present day Oloibiri State). By 1958, Nigeria made her first export shipment of 5,000 barrels per day (bpd). From this humble beginning, Nigeria is today ranked the largest oil producing nation in Africa, the 6th largest among Organization of Petroleum Exporting Countries (OPEC) and the 10th largest in the World (EIA 2010) with considerable industry asset (Table 1).

Over 90% of the oil industry operation in Nigeria is in the Niger Delta – a 70,000 km^2 Wetland in the Southern tip of the country (Figure 1).

A major characteristic of the Niger Delta Oil Province is that the fields are generally small and a large number of pipelines criss-cross the area.

There is a network of 5,001 km of pipeline consisting of 666 km of crude oil and 4,315 km of multiproduct pipelines. This pipeline network forms a mesh with the Pipeline Product and Marketing Company's (PPMC) over 12,000 km

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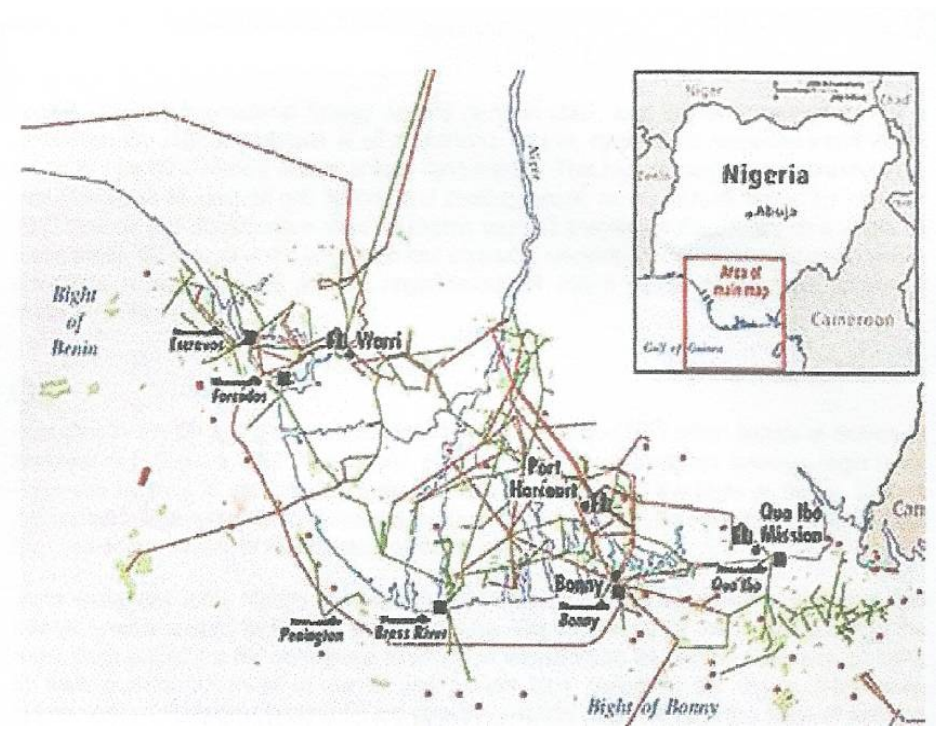
Table 1: Nigeria Oil Industry Asset

Reserves	36.20 billion barrels of Oil167 trillion cubic feet of Gas
Oil Fields	500 fields (55%of which are on-shore)
Wells	5300 (1418 active)
Pipelines	27 Km
Terminals	7
Flow Stations	112
FPSO	6

Figure 1: Niger Delta, Nigeria Showing Some Oil Infrastructure



of pipeline that interconnect the 22 petroleum storage depots in the country, the four refineries (Port Harcourt I and II, Kaduna and Warri), the offshore terminals at Bonny and Escravos and the jetties at Atlas Cove, Okrika and Warri (Onuaha, 2008; Achebe *et al.*, 2012).

Although pipelines are amongst the safest and most economical means of transporting bulk liquid over long distances (Din *et al.*, 2011), the integrity of pipelines is a matter of serious concern for the oil and gas Industry. Keeping pipelines safe, reliable and efficient is essential to minimizing the risk of high incident events that can have devastating impact on life, reputation, production and environment with inherent loss of revenue to the local and national economies.

Many pipelines in the Niger Delta are beginning to show their age through decreased reliability (Table 2) and maintaining their integrity is a constant challenge.

Table 2: Age and performance Rating of Nigeria Main Oil pipelines

Age (years)	Reliability (%)	% total National Length
< 20	46	27
20-30	29	32
< 30	25	41

Source: Achebe, et. al. (2012)

Apart from the menacing third party activity in the Niger Delta pipeline sabotage, oil bunkering, oil vandalism and terrorism (Alawode and Ogunleye, 2011), it has been well documented that corrosion in gas, liquid and multiphase transmission pipeline is a significant problem that has caused extensive damage to pipelines and operating facilities (Irorukpo, 1998; Lagad and Srinivason, 2013).Corrosion is the most prevalent type of defect accounting for practically over 95% of metal loss in pipelines (Slesarev and Sukhorukov, 2008). It is note worthy that the factors which create deterioration in pipelines do not affect the pipeline equally at all locations and the corrosion does not grow at the same rate throughout a pipeline.

In-Line Inspection (ILI) tools, also commonly called pipeline inspection gauge or 'pig' are devices used by the pipelines industry to survey mainly the internal condition of the pipeline wall. Intelligent pig, a tool with the capability of mapping anomalies, is widely used to detect, locate and measure the size of corrosion defect in a pipeline using high resolution Magnetic Flux Leakage (MFL), Ultrasonic Testing (UT) or sometimes a combination of the two. The technology delivers a potential for extensive evaluation and comprehensive analysis fundamental and sustained pipeline safety, effective integrity management and optimized operation (Pennington, 1991).

An analysis of inline inspection data from a 47 km, 24 inch diameter crude oil pipeline in the Niger Delta forms the basis of this paper. The objective is to determine the current integrity of the pipeline relative to the operational regime and assess the need for any remedial measure to ensure future safe operation of the pipeline.

MATERIALS AND METHODS

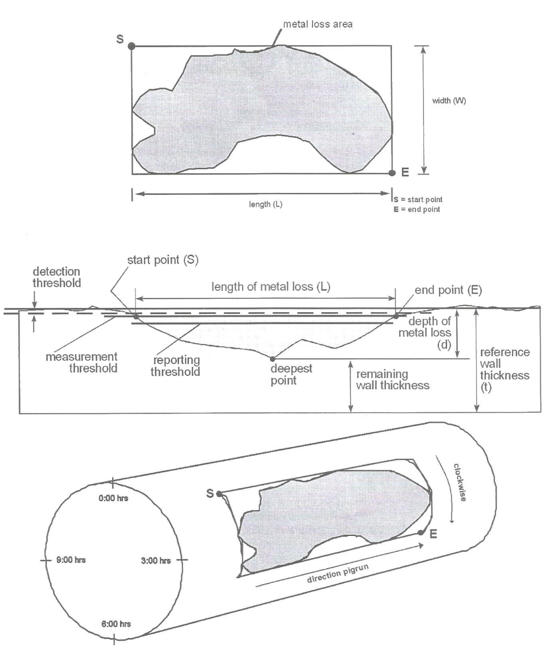
The purpose of an in-line inspection of a pipeline is the assessment of its integrity. Modern integrity assessment follows a fitness-for-purpose approach, an important input being the detection, sizing and location of flaws and defects within the pipe walls. The most widely performed inspections relate to geometry inspection, metal loss and lately also crack inspection (Barbian and Belar, 2012). Information provided by ILI tools basically consist of geometry data regarding a flaw or anomaly found namely:

- Length, L,(how long is a flaw from beginning to end, extent in the direction of the pipe)
- Depth, d, (how deep is the flaw, deepest point)
- Width, W, (how wide is the flaw, circumferential extent)
- Circumferential position (orientation, O'Clock position of a flaw)
- Longitudinal position (Figure 2).

This set of data is then used to analyze the integrity of a line.

The 24 inch diameter (carbon steel) pipeline conveying crude oil 47 km from a platform to a

Figure 2: Location and Dimensions of Metal Loss Anomaly



Source: POF, 2009

central terminal was commissioned in 1990. Approximate carrying capacity is 102,000 barrels of oil per day. An intelligent pigging inspection (magnetic flux leakage tool) was carried out 14 years after commissioning. In practice, it is often assumed that although corrosion can start at anytime the pipeline is in use, it is usually 10 years after the pipeline date of construction, that significant deterioration can be expected (Jones and Hopkins, 2008). The inspection vehicle of magnetic field strength 200 Oe in a 9.8 mm pipe was configured with sampling frequency of 3.3 mm. Inspection was within 48 hours.

RESULTS AND DISCUSSION

A total of 537,563 metal loss features were recorded on the inspection survey (Table 3). These are distributed throughout the pipeline. Metal loss features as classified by POF (2009) are shown in Table 4. Majority of the features in this study are internal and characteristic of general corrosion, located around the 6:00 O'Clock orientation. Although it is important to take note of every metal loss feature in a pipeline,

Table 3: Statistics of Metal Loss Features

Total number of metal loss defects537563	
Number of Internal metal loss defects	536614
Number of External loss defects	949
Number of metal loss defects with depth 0-9%	214891
Number of metal loss defects with depth 10-19%	261564
Number of metal loss defects with depth 20-29%	53155
Number of metal loss defects with depth 30-39%	7338
Number of metal loss defects with depth 40-49%	580
Number of metal loss defects with depth 50-59%	35
Number of metal loss defects with depth 60-69%	0
Number of metal loss defects with depth 70-79%	0
Number of metal loss defects with depth 80-89%	0
Number of metal loss defects with depth 90-100%	0

Johnson and Kolovich (2000) are of the opinion that corrosion should be characterized as significant only if and when the maximum depth is greater than 50% of wall loss. 35 Metal loss features in the 47 km pipeline have depth peak greater than 50%. However, only 12 of such features are highlighted in this study (Table 5). This is because although not truly clusters, they are so closely spaced (11 of them occurring within a 2.4 km space) that they require special attention. All 12 features also plot on the general corrosion field in the W/A; L/A plot (Figure 3).

An important observation in this analysis is that all the significant metal loss features (corrosion sites) are within 14 km absolute distance from the pig launch.Internal corrosion is

Table 4: Metal Loss Anomaly Classification

Anomaly Dimension class	Definition
General	{(W3A) and L>|3A|}
Pitting	{(1A<W<6A) and (1A<L<6A) and (0.5<L/W<2) and not{ (W>3A) and (L<3A) }
Axial Grooving	{(1A<W<3A) and (L/W>2)}
Circumferential Grooving	{(L/W<0.5) and (1A>L<3A)}
PinHole	{(0<W<1A) and (0<L<1A)}
Axial Slotting	{(0<W<1A) and (L>1A)}
Circumferential Slotting	{(W<1A) and (0<L<1A)}

Note: The geometrical parameter A, is linked to the Non-Destructive Examination (NDE) method in the following manners:

- If t < 10mm then A= 10mm
- If t > 10mm then A= t

Where t is the nominal pipe wall thickness.

Source: POF (2009)

Figure 3: W / A versus L / A Plot. Graphical Presentation of Metal Loss Anomalies Per Dimension Class (After Pof2009) Showing Metal Loss From This Study as General Corrosion

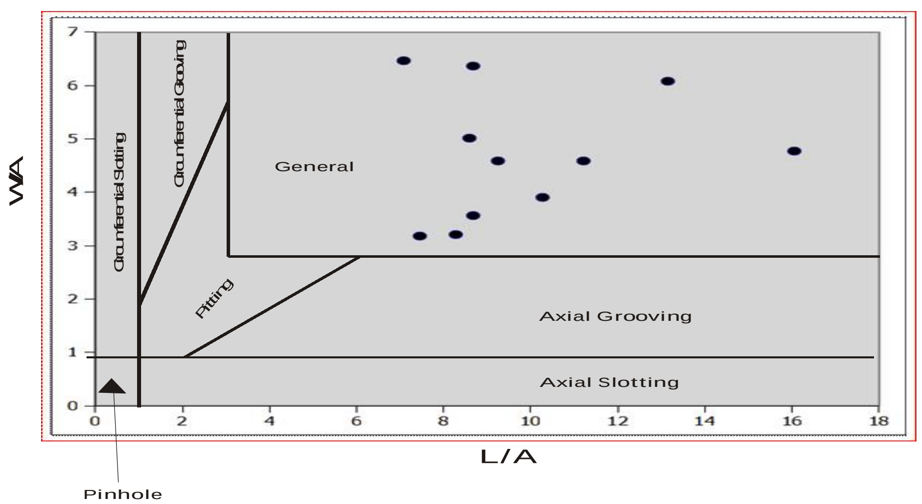


Table 5: Statistics of 12 Highlighted Metal Loss Features

	1	2	3	4	5	6	7	8	9	10	11	12
Orientation O'Clock	06.00	06.00	06.00	06.00	06.15	06.15	06.15	06.15	06.00	06.00	06.00	06.00
Axial Length (mm)	469	172	80	99	141	120	93	76	93	103	83	86
Circumferential Width (mm)	1560	51	34	49	65	49	38	69	68	39	32	50
Depth Peak (%)	60	55	51	51	50	56	51	55	58	52	50	51
Pressure Ratio (ERF)	0.86	0.64	0.55	0.57	0.60	0.60	0.56	0.55	0.55	0.58	0.55	0.56
Nominal Pipewall Thickness (mm)	12.9	12.7	10.7	10.7	10.7	10.7	10.7	10.7	10.7	9./8	9.8	9.8
Absolute Distance (m)	16.9	11,837	11,932	12,140	12,155	12,282	12,297	12,298	12,477	12,721	13,538	14,228

an electrochemical process and one of the first line of defence against it for transmission in a pipeline is to ensure that the product being transported is dry, de-aerated natural gas and moisture-free crude oil and petroleum products are not corrosive.For corrosion to occur there must be moisture, Carbon dioxide, oxygen and some other reduction reactants. According to Cvitanovic *et al.* (2010), internal corrosion in liquid hydrocarbon pipelines usually follows a distinctive distribution reflecting the origin and location of free water within the pipeline. Four main consistent patterns are as follows:

1) Water Carry Over – where water enters the pipeline as separate phase and creates erosion in the bottom of the line immediately downstream of the inlet.

2) Water Separation – water enters the pipeline as a water-in-oil emulsion which breaks down over time to cause corrosion in the bottom of the line some distance from the inlet.

3) Water Pooling – the corrosion distribution in a pipeline can be modified by water pooling at low points whether the origin is from carry over or separation.

4) Water Hold Up – if the elevation profile of a pipeline includes steep up-slopes in the direction of flow, water hold up can occur at the foot of these slopes.

The first significant metal loss feature occurring only 16.9 m absolute distance from inlet must be as a result of water carry over. Both the axial length and the circumferential width of the feature (469 mm and 1560 mm, respectively) indicate massive reduction reactants and intense activity (reaction).

No other significant metal loss feature is observed after this until kilometer 11.84. Eleven (11) other significant (›50%) features occur within the 2.4 km stretch between 11.84 km and 14.22 km (Table 5). Water separation caused by a breakdown in the water-in-oil emulsion is probably responsible for the metal loss features here. It is the authors' opinion that this is most likely as a 'result of a drop in the transmission velocity'.

As demonstrated by Nesic *et al.* (2005), 1 – 2% water can be successfully entrained even in light crude provided the flow rate of the crude stream is maintained at a velocity greater than 1 m/s. As the crude oil flow rate drops below 1 m/s there is a rapid drop in the water entrainment capability of crude oil and for light crude flowing at very low velocities, even 0.2% water entrainment may be difficult (Marsh *et al.,* 2008).

Overall, the current integrity of the studied pipeline can be rated high. Although several metal loss features have been detected, less than 0.01% of the 47 km pipeline can be said to have shown significant deterioration after 14 years of operation. This is in an area where a similar pipeline (20 inch diameter, 38 km carbon steel pipeline) showed extensive and severe wall loss, up to 55% with an indicated corrosion growth rate of 4 mm/yr only after two years of operation. The pipeline was declared unmanageable by a study carried out 3 years later which also revealed the likelihood of failure within the following five years and had to be replaced (Shell, 2004).

The analysis of the ILI data in this study has clearly revealed that efficiency of processing the product (how well dehydrated or de-aerated the oil or gas is) and how constant the transmission velocity and pressure are maintained throughout the pipeline are, more than other environmental factors, the determinants of the rate of deterioration of a pipeline.

CONCLUSION

Over 5000 km of pipelines criss-cross the Niger Delta Oil Province in Nigeria. Another 10,000 - 15,000 km transport various refined products across the country. Thus, over 20,000 km of pipelines are in service in Nigeria. Most of these pipelines are old. The reliability and fitness-for-purpose of some of them have greatly declined and integrity remains a major issue.

As a pipeline ages and is continuously in use, it can be affected by a range of corrosion mechanisms which lead to reduction in its structural integrity and eventual failure. In Line Inspection (ILI) is one of the most reliable means of assessing the integrity of pipeline. Although repeated pigging inspection provides historical data utilized to identify locations where changes have occurred over time and thus determine the corrosion growth rate, the result of a single ILI run then gives a snapshot of the current condition of the line and identifies locations that require remediation.

In this analysis of Magnetic Flux Leakage (MFL) ILI run of a 24 inch diameter, 47 km crude oil pipeline, it is noted that “water carry over” into the pipeline and “water separation” in the pipeline during transmission appear to be the major causes of the metal loss features observed.

Although the integrity of the pipeline is rated high (after 14 years of operation) a challenge is posed for pipeline and corrosion engineers to determine more precisely the flow condition leading to corrosion and conversely the conditions leading to entrainment of the free water layer by the flowing oil phase in order to maintain effective integrity, safety and optimized operation.

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