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Development of a Model for Predicting the Lifespan of Crude Oil Conveying Pipes

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***Abstract*-** The rate of pipe bursting which is a frequent occurrence in Nigeria has led to losses of fuel and destruction of pipelines. This is very high and needs attention. In this work, causes of pipe bursting were identified and a model was developed to predict the optimum replacement due date for any installed pipe in the oil field. The previous installation record of failures of different thicknesses used and their durations were collected by the use of questionnaires, these were considered with a developed empirical model. A computer program with the use of "Q" Basic programming language was used to test the accurate result. It was discovered that the wear rates of the pipelines for schedule 40, 80 and 160 in inches/year were 0.00023, 0.00029 and 0.0019 respectively. The rate of wear increased drastically for pipe schedule 160 due to very high pressure. Consequently, the results showed that it would require frequent attention to minimize the pipeline rupture and losses of fuel. Thus, the model developed made it easy to predict the lifespan of crude oil conveying pipelines with the sole aim of avoiding unprecedented failure that used to happen in the oil sector of the national economy.

***Keywords*-** *Conveying Pipeline, Crude Oil, Lifespan, Model Development, Software Development*

I. INTRODUCTION

Pipeline transportation of crude oil is the method of conveying oil through pipes. The commonly used method for fluid transportation is by forcing the fluid through a piping system from one point to another [1; 2]. Reference [3], also stated that pipe of rounded section is mostly used since the shape offers both the greater structural strength and greater cross-sectional area per unit of the wall surface than any other shape unless otherwise stated, that the phrase flow line in this project is referred to as closed conduit of rounded section and constant internal diameter. Statistically, it is not reasonable with present engineering practice to expect no failure from fabricated millions of pipeline parts even though, the number of pipeline failures may be small, it is very significant because it may cause damages to lives and the environment at large [4; 5]. Failure analysis has been defined as the logical, systematic examination of an item, its construction, application, and documentation to identify the failure index mode to determine the failure mechanism and its basic cause [6]. The literature of this research covered background, pipeline design, piping network, codes and specifications, piping standards, unfired pressure vessels, different sorts of pipe flow models and applications, diagnostics of metallic piping, advantages of the diagnostics and mathematical modeling. The need for the transportation of crude oil from the production region to the consuming area throughout the country has caused series of a network of transmission pipelines and that offshore and onshore productions are as well very significant as revealed by [7; 8]. Reference [9; 10] added that pipes and channels have generally brought key advantages to those who had them, effective pipelines or aqueduct projects required the right combination of economic and technical resources. Since many diverse industries use pipelines for different purposes, the design requirements are different and the types of pipe materials vary. In the petroleum and natural gas industry, steel pipe with welded joints is most common [11]. "Using high pressures, steel pipes make it possible to have fewer booster stations along the line, and steel's ductility enables it to bend and withstand considerable impact without fracturing" [12]. In the research conducted by Reference [13; 14; 15], they explained that a piping network is simply several piping components so connected that the flow to any component may come from several branches, such piping system can be extremely complicated, for example, the series of flow lines that transport crude oil from different wellhead to the flow station/refinery. The number piping junctions, the number of different piping loss elements and the number of branches involved may be quite large and the problem can be quite unwieldy. They added that the methods of analysis when multiple piping components as seen inflow line of crude oil are combined in various series and parallel arrangements. Piping components in series for both compressible and incompressible fluid flows have been considered and studied with different approaches.

Also, the method of combining losses of piping components like lines, bolt flanges, spurs, gaskets, elbows, risers, etc. arranged in series through the use of a common reference area have been put into consideration [16]. However, when a more complex network of pipes are encountered, additional methods of solution must be considered; for example: it is not always possible to solve an incompressible flow network problem by the usual forward type solution, wherein one starts at the piping inlet and proceed towards the exit bypassing successively through each piping element [17]. Reference [18; 19], established the fact that a pipeline is designed according to codes and specifications, those specifications describe nearly everything to do with the design, such as which materials to use, working stresses, seismic loads, thermal expansion, other imposed internal or external loads, as well as fabrication and installation. In addition, the design depends on factors relevant to the specific pipeline, including the fluid(s) to be transported (oil/gas/solids, single/multi-phase), the length and required capacity, the environment (warm/cold climate, overland/buried/subsea, urban/countryside), and operational conditions (need for valves, compressors, pumps, surge chambers, storage capacity) [20].

Reference [21 and 22] also stated that codes for various piping services were developed by nationally recognized engineering societies, standardized bodies and trade associations. The sound engineering practices incorporated in these codes generally cover minimum safety requirements for the selection of materials, dimensions, design, fabrication erection and testing of piping systems. Through interpretation and revision, these codes continually reflect the knowledge gained through experience, testing and research. They went further to say that, generally, piping codes form the basis for many state and municipal safety laws. Compliance with a code that has attained this status is mandatory for all systems included within the justification. Although some of today's piping installations are not within the scope of any interest or safety and as a basis of contract negotiations.

The concerned piping only to the extent of flanged, spur or threaded connection to the pressure vessels except, that the entire section was applied in those special cases where unfired pressure vessels were made from pipes and fittings. The American Society of Mechanical Engineers (ASME) code for pressure piping was at present a non–mandatory code in the United State except, where U.S legislative bodies and Canadian provinces have adopted these codes as legal requirements. Reference [23], added that the minimum safety requirements of these codes have been accepted by the industries as a standard for all piping outside the jurisdiction of other codes. They also explained the simplest way to classify pipe flow models by specifying how many separate fluids they can deal with simultaneously as described in Table 1 (single – phase, two – phase or three – phase), and by whether they are able to describe time-dependent phenomena (transient or purely steady-state).

TABLE I. CLASSIFICATIONS OF PIPES FLOW

Standard	Mechanical (structural) service pipe, low – pressure service pipe, refrigeration (ice – machine) pipe, ice – rink pipe, dry – kiln pipe.
Pressure	Liquid, gas, or vapour, service pipe, service for elevated temperature or pressure or both.
Line	Threaded or plain end, gas, oil, and steam pipe.
Water well	Reamed and drifted, water – well casing, drive pipe, driven well pipe, pump pipe, turbine pump pipe.
Oil country tubular goods	Casing, well tubing, drill pipe.
Other pipes	Conduit, piles, nipple pipe, striker pipe, bed – stead tubing.

Source: [23]

Developing a model without recommendation to prevent similar and subsequent failure does not justify a good model due to the fact that; there exist a possibility of unforeseen heating, unreported collision and unanticipated vibration that might contribute to premature failure of pipelines. Therefore, certain preventive measures were put into consideration, which are: safety precautions for proper guidelines before, during and after installations, investigations to uncover the root cause of premature failure of pipeline and the analysis to prevent any re – occurrence, and health, safety, and environmental quality control management of live(s), properties and environment to prevent injury and untimely death due to unseen pipeline failure are properly put in place. The research work would help to avoid the occurrence of unprecedented failure that leads to accident in the oil sector. It would also help the oil production company to know the exact time to change their pipelines, once they have reached their lifespan which has already been predicted by the use of the model developed.

The study covered oil fields operated by some oil companies selected at random for proper research and comparison of data in the Niger – Delta region of Nigeria. These oil wells were selected randomly due to limiting factors that would not allow easy accessibility to all the oil fields and flow stations. For the sake of anonymity and confidentiality in the research work, the selected companies were represented as companies A, B, C.

II. METHODOLOGY

The study involved a full understanding of pipeline working principles. To this effect, a need arose to have an overview of the root cause of failure. The methods embraced the procedure used to achieve the objectives. Several textbooks and past studies on pipes, its specifications, and its detail analysis were thoroughly studied.

A. Field Survey

The following questions formed the major part of the questionnaires, as part of the research survey, administered to the selected team of field workers and inspection officers in Bayelsa, Rivers and Edo State in Nigeria:

a) When were the pipes installed?
b) Were the pipeline parts properly installed?
c) What are the safety precautions to maintain pipelines?
d) What are the features and properties of the flow of a well-installed pipeline?

e) What are the testing parameters/specifications to confirm whether the pipeline is ready for operation or not?
f) When did operation commence on the pipelines?
g) What was the length of the pipeline used in transportation?
h) Was the pipeline meant for crude oil transportation alone?
i) If no, what are the other products on the pipelines?
j) How frequent were the pipelines used to convey crude oil?
k) Was the pipeline operation effective and efficient for its purpose?
l) If yes, what are your observations about its features?
m) What are the environmental changes that could affect the pipelines?
n) What was the service maintenance management employed?
o) What was the normal service pressure of the crude oil flowing in and out of the oil well?
p) What are other factors observed that could affect the efficiency of the pipelines?
q) How long has the pipeline been in operation?
r) What are the features of the aging pipeline before it corrodes?
s) How long can the pipeline be in service before replacement?
t) What are other factors that can result in an emergency replacement of any part of the pipeline?
u) Can the lifespan of a good pipeline be predicted under normal circumstances?

The surveys were carried out in Bayelsa, Rivers and Edo State, Nigeria as represented by Comp A, Comp B and Comp C respectively. While on site, different sections of the pipelines were examined, most especially the parts that failed in service. An extensive vetting of past records of all the pipeline activities, personal observations and interviews were also adopted.

B. Collection of Data

Reduction in thickness (X inches), initial thickness(I_t inches), final thickness(F_t inches), pipe installation date/year(T_c year), pipe removal date/year (T_f year) and pipe duration (G_t year) were the required data collected for each pipe schedule (40, 80 and 160) and pressure (low, high and very high). Other specifications of set of quantities and values from companies A, B, and C are as shown in Tables 2, 3 and 4.

TABLE II. DATA DESCRIPTIONS AND VALUES FROM COMPANY A

DATA DESCRIPTION	DESCRIPTION/VALUE	UNITS
Type of System	Hazardous liquid	-
Accident type	Pipeline failure and leakage	-
Material released	Crude oil	-
Pipeline pressure	606 pounds per square inch (606p/i^2). Gauge at the site of failure	Psi
Maximum operating pressure	780 Minimum Operating Pressure (MOP)	Psi
Pipe outer diameter	24 inches	In
Pipe specification number	API 5L, (X – 52)	-
Wall thickness (for 40, 80 and 160)	0.100, 0.125, 0.250 inches	In
Type of Pipe	Steel pipe	-
Duration/Years in service before failure (for schedule 40,80 and 160)	1975-2005, 1972-2009, 1986-2010	Years
Reduction in thickness (for schedule 40, 80 and 160 respectively)	0.003, 0.0052, 0.019	Inches

Source: Study, 2019.

TABLE III. DATA DESCRIPTIONS AND VALUES FROM COMPANY B

DATA DESCRIPTION	DESCRIPTION/VALUE	UNITS
Maximum operating pressure	800	Psi
Outer diameter pipe	12.750 inches	In
Specified minimum yield strength	42,000	Psi
Normal wall thickness of the pipe (for 40, 80 and 160)	0.100, 0.125, 0.250	In
Design factor (Quality factor E)	0.72	-
Temperature rerating factor	1.0	-
Maximum depth of corroded area	0.080	In
Measured longitudinal extent of corroded area	6.00	In
Pit depth percentage	32.0	%
Constant for calculated of corrosion length	1.229	-
Constant for maximum allowable pressure	3.001	-
Duration of pipes (for 40, 80 and 160)	1982-2009, 1974-2007, 1974-2003	Years
Reduction in thickness (for schedule 40, 80 and 160 respectively)	0.0067, 0.0103, 0.038	Inches

Source: Study, 2019.

TABLE IV. DATA DESCRIPTIONS AND VALUES FROM COMPANY C

DATA DESCRIPTION	DESCRIPTION/VALUE	UNITS
Pipe outer diameter	8.625 inches	In
Wall thickness of the pipe (for 40, 80 and 160)	0.100, 0.125, 0.250 inches	In
Specified minimum yield strength	35.000	-
Maximum operating pressure	1440	Psi
Operating temperature	70	°F
Duration of pipes (40, 80 and 160)	1979-2010, 1974-2010, 1997-2005	Years
Reduction in thickness (for schedule 40,80 and 160)	0.010, 0.0155, 0.057	Inches

Source: Study, 2019

C. *Model Development*

Rate of wear of the pipe (R_t) is the ratio of the change in pipe thickness to the change in the duration of pipe. It is measured in inches/year. The Figure 1 shows the relationship between the pipe thickness and the year of installation while Figure 2 explains the computer-implementable instructions for software application.

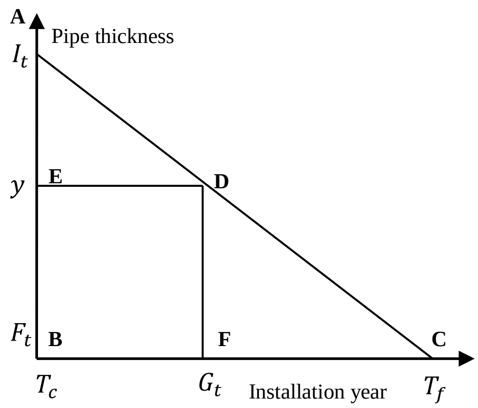

Figure 1. Interpolation Gradient

Considering triangle ABC

$$R_t = \frac{I_t - F_t}{T_f - T_c} \tag{1}$$

Also considering triangle DCF or ADE

$$R_t = \frac{y - F_t}{T_f - G_t} \tag{2}$$

Equating equations (i) and (ii)

$$R_t = \frac{I_t - F_t}{T_f - T_c} = \frac{y - F_t}{T_f - G_t} \tag{3}$$

Where:

I_t is the initial thickness of the pipeline at the time of installation.

F_t is the final thickness of the pipeline (on inspection).

y is the reduction in thickness (on inspection).

T_c is the time/date pipeline was installed.

T_f is the time/date pipeline was removed.

G_t is the duration of pipe.

R_t is the rate of wear of the pipe.

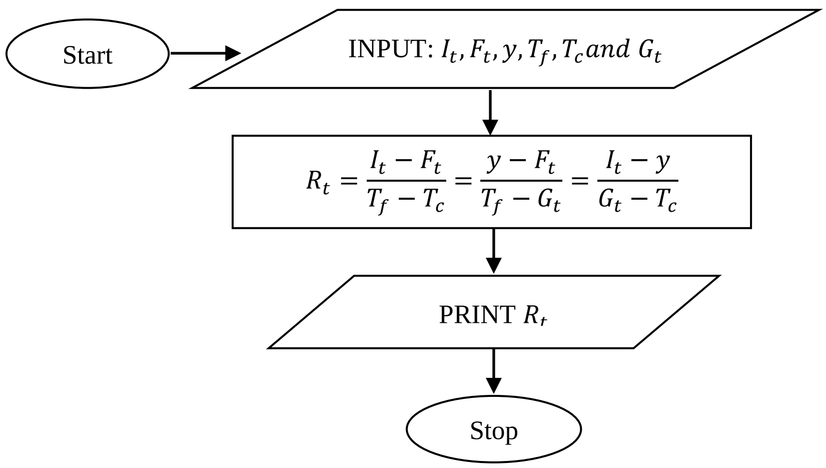

Figure 2. Algorithm Development

III. RESULTS AND DISCUSSION

Tables 5, 6 and 7 summarized the data descriptions and values for companies A, B and C while Table 8 illustrated the average value of the data description and values for the three companies. The rate of wear of pipeline for schedule 40, 80 and 160 in inches/year were 0.00023, 0.00029 and 0.0019 respectively. It was discovered that the "pipe schedule 160" has the highest rate of wear. The pipe thickness is inversely proportional to the year of installation. Thus, as the year of installation increases, the thickness of pipe reduces due to high pressure of fluid flow. Therefore, it would require frequent attention most especially when the wear rate increases per year depending on the pressure of fluid flow to minimize the pipeline rupture and losses of fuel.

TABLE V. SUMMARY OF THE DATA DESCRIPTION AND VALUES FOR COMPANY A

Pipe Schedule	Pressure	Reduction in Thickness (X) inches	Initial thickness (I_t) inches	Final thickness (F_t) inches	Date/Year installed (T_c)	Date/Year removed (T_f)	Duration of pipe (G_t)
40	Low	0.003	0.100	0.0970	1975	2005	30
80	High	0.0052	0.125	0.1198	1972	2009	37
160	Very high	0.019	0.250	0.2310	1986	2010	24

Source: Study, 2019

TABLE VI. SUMMARY OF THE DATA DESCRIPTION AND VALUES FOR COMPANY B

Pipe Schedule	Pressure	Reduction in Thickness (X) inches	Initial thickness (I_t) inches	Final thickness (F_t) inches	Date/Year installed (T_c)	Date/Year removed (T_f)	Duration of pipe (G_t)
40	Low	0.0067	0.100	0.0933	1982	2009	27
80	High	0.0103	0.125	0.1147	1974	2007	33
160	Very high	0.038	0.250	0.2120	1974	2003	29

Source: Study, 2019.

TABLE VII. SUMMARY OF THE DATA DESCRIPTION AND VALUES FOR COMPANY C

Pipe Schedule	Pressure	Reduction in Thickness (X) inches	Initial thickness (I_t) inches	Final thickness (F_t) inches	Date/Year installed (T_c)	Date/Year removed (T_f)	Duration of pipe (G_t)
40	Low	0.010	0.100	0.09	1979	2010	31
80	High	0.0155	0.125	0.1095	1974	2010	36
160	Very high	0.057	0.250	0.193	1997	2005	8

Source: Study, 2019.

TABLE VIII. AVERAGE VALUE OF THE DATA DESCRIPTION AND VALUES FOR COMPANIES A, B AND C

Pipe Schedule	Pressure	Reduction in Thickness (X) inches	Initial thickness (I_t) inches	Final thickness (F_t) inches	Date/Year installed (T_c)	Date/Year removed (T_f)	Duration of pipe (G_t)
40	Low	0.0066	0.100	0.0934	1979	2008	29
80	High	0.0103	0.125	0.1147	1973	2009	36
160	Very high	0.038	0.250	0.212	1986	2006	20

Source: Study, 2020.

IV. CONCLUSIONS

The study identified the causes of pipeline rupture and developed a model to predict the optimum replacement due date for any installed pipe in the oil field. The previous installation record of failures of different thicknesses and duration of pipes were used with the aid of questionnaire. The analysis of the data from companies A, B, and C were used to integrate the developed model while the computer programming language (Q-basic) was used for its implementation. The model developed made it easy to predict the lifespan of crude oil conveying pipelines with the sole aim of avoiding unprecedented failure that used to happen in the oil sector of the national economy. With the use of the model developed, it would check and avoid failures that occur in pipes which could save cost, lives and properties.

For further study in the cause of this work, other factors attached to the flow of crude oil in pipelines could also be used to predict the lifespan of pipeline conveying crude oil.

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