Saudi Journal of Engineering and Technology (SJEAT)
Scholars Middle East Publishers
Dubai, United Arab Emirates
Website: http://scholarsmepub.com/

ISSN 2415-6272 (Print)
ISSN 2415-6264 (Online)

Analysis of Natural Gas Pipeline Failure (A Case Study of a Typical Marginal Oil and Gas Field in Niger Delta, Nigeria)

Ugwunna A. D[1], Appah D[2], Evbuomwan B. O[3*]
[1]Centre for Gas, Refining and Petrochemicals, University of Port Harcourt, Port Harcourt, Nigeria
[2]Department of Petroleum and Gas Engineering, University of Port Harcourt, Port Harcourt, Nigeria
[3]Department of Chemical Engineering, University of Port Harcourt, Port Harcourt, Nigeria

Original Research Article

***Corresponding author**
Evbuomwan B. O

Article History
Received: 12.12.2018
Accepted: 20.12.2018
Published: 30.12.2018

DOI:
10.21276/sjeat.2018.3.12.1

Abstract: This paper aimed at carrying out a failure analysis on a typical gas pipeline in Niger Delta, Nigeria. The research analyzes the causes of failure of an existing pipeline which conveys 35MSCF/D of natural gas from the processing plant of marginal oil and gas field to a power generating station, 14km away. Non Destructive Testing (NDT) procedure, specifically, Ultrasonic Testing method was used to carry out the failure analysis on the pipe specimen. The pipeline thickness gauging alongside the flaw detention procedures carried out showed that the pipeline failed integrity test, therefore unfit for its intended purpose. The overall result shows that the major causes of the pipe failure are metallurgical/weld defect as well as corrosion along the welded line. The parameters obtained were used to compute the failure model for the pipeline.
Keywords: Pipeline, failure, metallurgical/weld, corrosion, natural gas.

INTRODUCTION

A pipeline is simply a line of interconnected pipes with pumps/compressors, valves, control devices used for the purpose of transportation of fluids. A pipe is a straight and pressure tight cylindrical hollow material which is used in the piping system to make pipelines. Pipelines are connected pipes which are installed for the purpose of transmitting gases, liquids, slurries, etc., from sources of supply to one or more distribution center(s) or to one or more large-volume customer(s) [1]. Pipelines are connected pipes which are installed for the purpose of transmitting gases, liquids, slurries, etc., from sources of supply to one or more distribution center(s) or to one or more large-volume customer(s) [1].

Natural gas due to its storage difficulties needs to be transported to its needed destination as soon as it is produced from the reservoir. There are a number of options for transporting natural gas energy from oil and gas fields to market [2]. Failure of an operating pipeline is a rare event. However when it does occur, it must be properly analyzed to prevent future reoccurrence [3]. Despite all the care taken during the design and construction of pipelines, there is always risk of damage to the pipelines from one way or the other. It may due to corrosion, mechanical defects, outside forces, cracks in the seam weld and operational factors etc [4]. Considering the extreme danger associated with exposure of natural gas to the immediate surroundings, it is therefore pertinent for the proper design of natural gas pipeline to avoid its failure which could lead to loss of life and properties. Generally, pipes are vulnerable to corrosion attack both internally and externally depending on the material and its interaction with the environment. Aside corrosion, manufacturing flaws, cracks, logistics damages etc can necessitate pipe failure in the nearest future. Therefore for safe operation of the pipelines, periodic inspections can be carried out to detect flaws or damages which could graduate to failure of the pipeline. This is necessary because failure of a pipeline especially, natural gas pipeline is a serious threat to the environment.

Recently, the pipeline transmitting natural gas from a typical marginal field in Niger delta, ruptured. The operating company did a sectional replacement of the ruptured section, therefore putting the pipeline to use again. The replaced section of the failed pipeline, which is 9.2 feet long, 6 inch diameter and 4mm thickness, is considered a specimen for this failure analysis.

Pipelines are usually made of steel pipes which do not degrade with time. Unlike automobiles, there are no moving parts that could cause tear and wear. But as the steel ages, some of the mechanical properties of the material will slightly decrease with time, therefore reducing the pipelines ability to tolerate anomalies. It is important to note that major causes of loss of integrity in pipelines are due to anomalies inherent in the pipe and not necessarily the age of the pipe. Pipeline is connected pipes installed for the purpose of transmitting gases, liquids, slurries, etc., from a source or sources of supply to one or more distribution centers or to one or more large-volume customers; a pipe installed to interconnect source or sources of supply to one or more distribution centers or to one or more large-volume customers; or a pipe installed to interconnect sources of supply [5].

Pipe is a tube with a round cross section conforming to the dimensional requirements for nominal pipe size as tabulated in ASME B31.8 and ASME. Gas transmission capacity in pipeline is mainly controlled by the size. Some equations has been developed by scientist mainly for sizing natural gas pipelines with respect to various flow condition

The equations are used to relate the volume of gas transmitted through a gas pipeline to the various factors involved, so as to decide the optimum pressure alongside the pipe dimensions. With the equations, some variables like pipe diameter and the wall thickness for a desired flow rate can be calculated and determined. Reviews have shown that the most common pipeline flow equation is the Weymouth equation, which is generally preferred for a smaller diameter lines (D≤15inch). While the panhandle equation and the modified Panhandle equations are usually better for larger-sized transmission line [6].

In this paper, a case study of a typical marginal oil and gas field located in Niger Delta, Nigeria is considered. Originally, the gas is transported through a 6" Schedule 40 pipeline to feed a power generating plant which is about 14km away. The said pipeline is characterized by incessant leakages as well as interruption of natural gas delivery to the consumer (Gas turbine power plant), therefore there is need for replacement of the existing pipeline, considering the causative failure factors in the design. The aim is also to carry out failure analysis on the pipe specimen to ascertain the cause of the rupture along the pipeline.

METHODOLOGY

Data collection and failure analysis on pipe

Data used for the pipeline failure analysis was obtained practically in the field, on a cut off pipe section from the gas pipeline. The sample part of a replaced pipe section which is used as a specimen for this research work has the following parameters.

- Pipe Outside diameter : 6" (152.4mm)
- Original Wall Thickness : 0.157" (4mm)
- Length of pipe specimen: 9.2ft
- Pipe specification: API 5LX
- Grade X-42
- SMYS: 290 Mpa (42,000 psi)
- SUTS: 414 Mpa (60,000 psi)

Figure-1 is the schematic diagram of the pipe specimen under review, showing a clear longitudinal weld which span through a length of 9.2 ft.

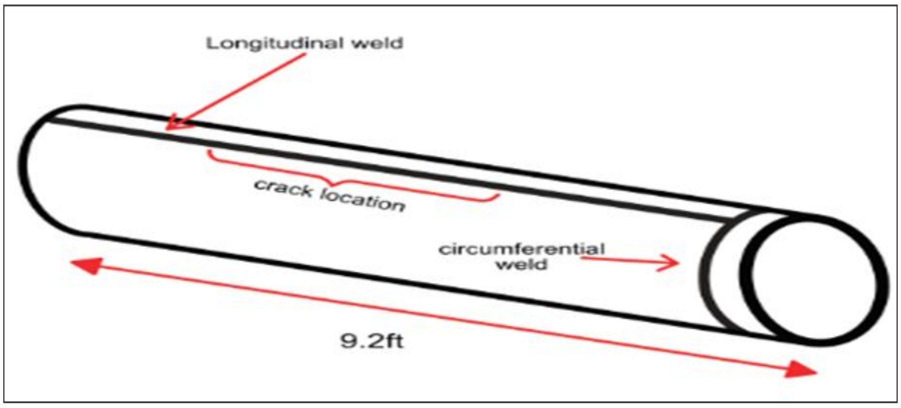

Fig-1: Schematic diagram of the pipe specimen

Thickness Measurement of the Pipe Specimen

Ultrasonic testing (UT) is a form of Non- Destructive Testing technique whose principle is based on the propagation of ultrasonic (sound) waves in the material to be tested. Its frequency ranges from 0.1-15Mhz, which is transmitted into the sample or specimen to detect internal flaws, metallurgical discontinuity and material thickness. UT can be used in steels, alloys, aluminum, concretes etc. In this analysis, Ultrasonic thickness (UT) machine was used to carry out thickness gauging measurements and flaw detection at different points of the pipe sample, otherwise known as UT spot check measurement.

The procedure for the UT thickness measurement includes:

- Preparation of the surface to be inspected by cleaning and removing loose scales, particles and paints
- Turn on the scanner/ device
- Calibrate the device using the calibration block
- Apply couplant on the surface to be analyzed. This is to enhance proper transfer of sound wave energy between the part to be inspected and the probe. Therefore allowing sound wave to pass through the pipe wall.
- Take readings on each point at one feet interval apart.

NOTE: A total of nine (9) reading were taking at one feet interval as shown in figure-2.

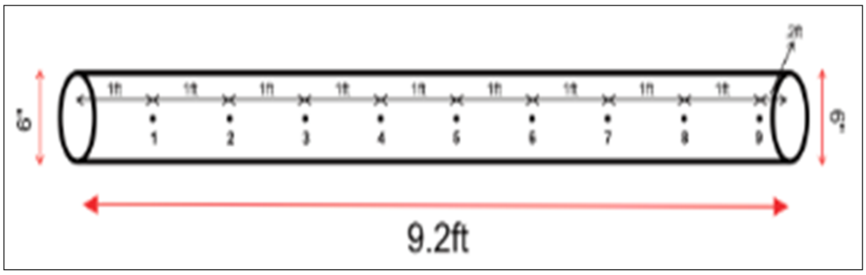

Fig-2: Marked and tested points of the pipe specimen

Wall thickness acceptance criteria

Minimum wall thickness of a pipe according to ASME B31.8

t_{min} = 0.875 x Nominal thickness
= 0.875 x 4mm =3.5mm

When, $t \geq t_{min}$, (Pass, accept)
$t < t_{min}$, (Fail, reject)

Determination of pipeline probability of failure, P_F

Pipeline probability of failure, $P(f) = \frac{PMS_D}{BP_D}$ .... (1)

Where,

PMS_D =Flow stress x Design Pressure x M (2)

Design Pressure = 2x f x SMYS x t/D (3)

$$M=\sqrt{\frac{1+0.8\,x\ L}{\sqrt{D\ x\ t}}} \quad (4)$$

DETERMINATION OF PIPELINE MAXIMUM SAFE PRESSURE AT DEFECTS (PMS_D)

$$\text{Flow stress}= \frac{\text{SMYS x 0.9}}{\text{SUTS}} = \frac{\text{290 mpa x 0.9}}{\text{414 mpa}} = 0.6304$$

Design Pressure = 2x f x SMYS x t/D
= 2 x 0.72 x 290Mpa x 4mm/152.4mm
= 10.96 mpa

$$M=\sqrt{\frac{1+0.8\,x\ L}{\sqrt{D\ x\ t}}}$$

M is dependent on the length of defect and the remaining wall thickness.

:. $PMS_D = 0.6304 \times 10.96$ mpa x M

$PMS_D = 6.915M$ (mpa)

DETERMINATION OF PIPELINE BURSTING PRESSURE AT DEFECTS (BP_D)

$$BP_D = 0.5(SMYS + SUTS)\frac{2 \times t}{D}$$

$$= 0.5\,(219 + 414)\frac{2 \times t}{D}$$

$$BP_D = 704t/D \text{ (mpa)}$$

At point 1, defect length L_m= 10mm, Measured thickness t_m = 2.35mm

$$M = \sqrt{\frac{1 + 0.8\,x\;10}{\sqrt{152.4\,x\;2.35}}} = 1.1928$$

PMS_{D1} =6.915 x 1.1928 = 8.248 mpa

$$BP_{D1} = \frac{704 \times 2.35}{152.4} = 10.8556 \text{ mpa}$$

$$P_{f1} = \frac{PMS_D}{BP_D} = \frac{8.248 \text{ mpa}}{10.8556 \text{ mpa}} = 0.7598$$

At point 2, defect length L_m= 28mm, Measured thickness t_m = 1.84mm

$$M = \sqrt{\frac{1 + 0.8\,x\;28}{\sqrt{152.4\,x\;1.84}}} = 1.5289$$

PMS_{D2} =6.915 x 1.5289 = 10.573 mpa

$$BP_{D2} = \frac{704 \times 1.84}{152.4} = 8.4997 \text{Mpa}$$

$$P_{f2} = \frac{PMS_{D2}}{BP_{D2}} = \frac{10.573 \text{ mpa}}{8.4997 \text{ mpa}} = 1.2439$$

At point 3, defect length L_m= 12mm, Measured thickness t_m = 3.44mm

$$M_3 = \sqrt{\frac{1 + 0.8\,x\;12}{\sqrt{152.4\,x\;3.44}}} = 1.191$$

PMS_{D3} =6.915 x 1.191 = 8.2357 mpa

$$BP_{D3} = \frac{704 \times 3.44}{152.4} = 15.8908 \text{ mpa}$$

$$P_{f3} = \frac{PMS_{D3}}{BP_{D3}} = \frac{8.2357 \text{ mpa}}{15.8908 \text{ mpa}} = 0.5183$$

NOTE: Same procedure was used to calculate for other points.

Determining the Linear Regression Model

Table-1: Calculating Linear regression of P_f on t_m and L_m

#	Probability of failure, P_f	Average Thickness, t_m	Defects length L_m
1	0.7598	2.35	10
2	1.2339	1.84	28
3	0.5183	3.44	12
4	0.4834	3.50	8
5	0.4936	3.56	11
6	0.6243	3.27	24
7	0.8704	2.47	18
8	0.6346	2.78	10
9	0.6253	2.89	12

Let, $Y=P_f$, $X_1=t_m$, $X_2=L_m$

The linear regression model equation

$$Y = a_0 + a_1X_1 + a_2X_2$$

Developing the normal equations

$$\sum Y = a_0N + a1\sum X_I + a_2\sum X_2$$

$$\sum Y.XI = a_0\sum X_1 + a1\sum X_1^2 + a2\sum X_1.X_2$$

$$\sum Y.X2 = a_0\sum X_2 + a1\sum X_1.X_2 + a2\sum X_2^2$$

In Matrix Form

$$\begin{bmatrix} N & \sum X_1 & \sum X_2 \\ \sum X_1 & \sum X_1^2 & \sum X_1.X_2 \\ \sum X_2 & \sum X_1.X_2 & \sum X_2^2 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \end{bmatrix} = \begin{bmatrix} \sum Y \\ \sum Y.X_1 \\ \sum Y.X_2 \end{bmatrix}$$

Table-2: Linear regression model computation

#	**Y**	**X_1**	**X_2**	**Y^2**	**X_I^2**	**X_2^2**	**$X_1.X_2$**	**$X_1.Y$**	**$X_2.Y$**
1	0.7598	2.35	10	0.5773	5.5225	100	23.5	1.7855	7.598
2	1.2339	1.84	28	1.5225	3.3856	784	51.52	2.2704	34.549
3	0.5183	3.44	12	0.2686	11.834	144	41.28	1.783	6.2196
4	0.4834	3.5	8	0.2337	12.25	64	28	1.6919	3.8672
5	0.4936	3.56	11	0.2436	12.674	121	39.16	1.7572	5.4296
6	0.6243	3.27	24	0.3898	10.693	576	78.48	2.0415	14.983
7	0.8704	2.47	18	0.7576	6.1009	324	44.46	2.1499	15.667
8	0.6346	2.78	10	0.4027	7.7284	100	27.8	1.7642	6.346
9	0.6253	2.89	12	0.391	8.3521	144	34.68	1.8071	7.5036
Σ	**6.2436**	**26.1**	**133**	**4.7868**	**78.54**	**2357**	**368.88**	**17.051**	**102.16**

Substituting the values from Table-2 into the normal equations.

$$\begin{bmatrix} 9 & 26.1 & 133 \\ 26.1 & 78.54 & 368.88 \\ 133 & 368.88 & 2357 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \end{bmatrix} = \begin{bmatrix} 6.244 \\ 17.051 \\ 102.16 \end{bmatrix}$$

By Gaussian Elimination method: $\mathbf{a_0 = 1.3705}$; $\mathbf{a_1 = -0.2970}$; $\mathbf{a_2 = 0.0125}$

Therefore the linear regression model for the probability of failure vis-à-vis measured wall thickness and defect length for the pipe specimen is given as follows.

$$\mathbf{P_f = 1.3705 - 0.2970t_m + 0.0125L_m} \quad (5)$$

RESULTS AND DISCUSSION

Failure Analysis Result on pipe specimen

Table-3: Ultrasonic thickness gauging results

#	Length (Ft)	Wall Thickness readings, t (mm)				$\dot{t}$ (mm)	Remark
		12^{o}Clock	3^{o}Clock	6^{o}Clock	9^{o}Clock		
1	1	1.97	2.19	1.97	3.26	2.35	Fail
2	1	0.00	2.01	1.92	3.41	1.84	Fail
3	1	3.31	3.59	3.31	3.54	3.44	Fail
4	1	3.40	3.57	3.49	3.54	3.50	Pass
5	1	3.58	3.53	3.58	3.54	3.56	Pass
6	1	3.22	3.21	3.41	3.22	3.27	Fail
7	1	1.87	3.41	1.92	2.66	2.47	Fail
8	1	2.11	2.69	3.51	2.82	2.78	Fail
9	1	3.21	2.16	3.02	3.18	2.89	Fail

Table-4: Probability of failure computation results

#	Average Thickness, t_m	Defects length L_m	Probability of failure, P_f	
1	2.35	10	0.7598	75.98%
2	1.84	28	1.2339	123.39%
3	3.44	12	0.5183	51.83%
4	3.50	8	0.4834	48.34%
5	3.56	11	0.4936	49.36%
6	3.27	24	0.6243	62.43%
7	2.47	18	0.8704	87.04%
8	2.78	10	0.6346	63.46%
9	2.89	12	0.6253	62.53%

Table-5: Measured thickness, (t_m) and probability of failure (P_f)

(t_m)	2.35	1.84	3.44	3.50	3.56	3.27	2.47	2.78	2.89
(P_f)	0.7598	1.2339	0.5183	0.4834	0.4836	0.6243	0.8704	0.6346	0.6253

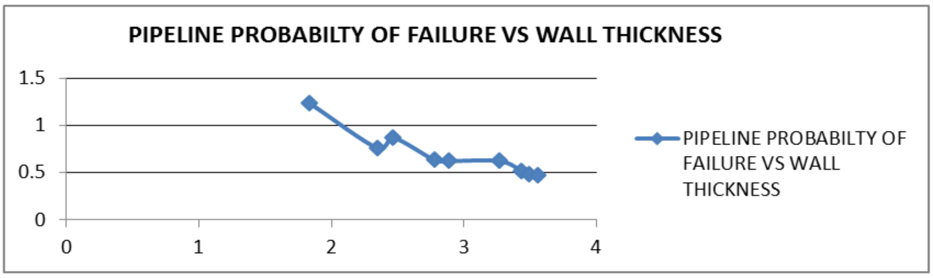

Fig-3: A plot of the measured thickness and its probability of failure

Table-6: Summary of the pipe specimen analysis

#	D(mm)	t(mm)	t_m (mm)	L_m (mm)	SMYS (Mpa)	SUTS (Mpa)	M	$PMSP_D$ (Mpa)	PB_D(Mpa)	P_f	
1	152.4	4.00	2.35	10	290	414	1.1928	8.248	10.8556	0.759	**75.9%**
2	152.4	4.00	1.84	28	290	414	1.5289	10.573	8.4997	1.234	**123%**
3	152.4	4.00	3.44	12	290	414	1.191	8.240	15.891	0.518	**51.8%**
4	152.4	4.00	3.50	8	290	414	1.1301	7.815	16.1679	0.483	**48.3%**
5	152.4	4.00	3.56	11	290	414	1.1738	8.1168	16.445	0.494	**49.3%**
6	152.4	4.00	3.27	24	290	414	1.364	9.431	15.106	0.624	**62.4%**
7	152.4	4.00	2.47	18	290	414	1.319	9.127	10.486	0.870	**87.0%**
8	152.4	4.00	2.78	10	290	414	1.178	8.149	12.842	0.635	**63.5%**
9	152.4	4.00	2.89	12	290	414	1.207	8.348	13.350	0.625	**62.5%**

Where,

D = Pipe diameter, mm, t = Original wall thickness of the pipe, mm,
t_m = Measured Thickness, M= Folia bulging factor
L_m = Length of defects, mm, SMYS= Specified Minimum Yield stress
SUTS= Specified Ultimate Tensile stress, M= Folia bulging factor,
$PMSP_D$= Pipeline Maximum Safe Pressure at defect, mpa,
PB_D = Bursting pressure at defect, mpa

DISCUSSION

Failure Analysis

The results of the failure analysis showed that there were some metallurgical defects on the longitudinal seam weld, which could not withstand the operational conditions subjected to the pipeline. This is evident on the following facts:

From visual inspection

There are evidences of pitting, rust and cracks, at both the internal and external surface of the pipe. These are mostly dispersed along the welded line. For example;

- The presence of the conspicuous pits on the longitudinal seam weld as compared to other areas along the pipe specimen. Pitting corrosion on the outside surface measuring 3.2mm deep as seen along the welded line and cracked section.
- The presence of cracks clearly seen on the longitudinal seam weld both on the inside and the outside of the pipe, spanning through the weld line measuring 41cm
- Deviation of cracks measuring about 25mm on the external surface is evident.
- Visible corrosion and cracks at the internal surface of the pipe.

From the UT thickness gauging result

- Out of 9 points where circumferential thickness measurement were taken, a total of seven (7) points (i.e 1,2,3,6,7,8,9) failed the thickness criteria test, because these values are below 3.5mm. At those points, the probability of failure is high.
- Only two points 4 and 5 passed the thickness measurement test. The measured thicknesses at those points are above the benchmark of 3.5mm.
- UT flaw detection procedure at different points of the specimen shows series of discontinuities along the longitudinal welded line.
- The plot of P_f and $t_m$also proved the assertions on a, b and c above. The smaller the wall thickness the higher the probability of failure and vice versa.

For the pipeline failure analysis, a ruptured pipe segment from the pipeline, measuring 9.2ft long with a diameter 0f 152.4cm as shown in figure 1, was used to determine the cause of the leakage in the pipe line. If the probability of failure exceeds 1.0, failure is likely to occur [7]. The technical analysis was done using Ultrasonic Testing, UT which is one of the useful and versatile methods of Non Destructive Testing, NDT for determining discontinuities in pipelines as well as pipe wall thickness of corroded pipes. A spot check measurement was taken by UT thickness gauge meter at different points, at a distance of one feet interval apart as shown in figure 2. At each point, four readings were taken at the North, East, and South and West cardinal. Which translate to a total of 36 read points.An average of the four points at each circumference of the pipe specimen was determined and a total of nine (9) points was used as the bases for other calculations.

The wall thickness acceptance/rejection criteria for the pipe wall thickness were calculated as 3.5mm according to ASMEB31.8. As stated earlier, out of the average of nine points calculated, seven (7) points failed while two (2) points passed judging by the acceptance/rejection criteria. This means that the wall thicknesses of the seven points (1,2,3,6,7,8,9) falls below 3.5mm and points 4 and 5 falls above 3.5mm.

The probabilities that the pipeline will fail at those points were calculated considering the pipe maximum safe operating pressure and the bursting pressures at defect as shown table-5. A mathematical equation model for the probability of failure of the pipe specimen was determined, using the average thickness t_m and the defect lengths L_m as the independent variables and the probability of failure, P_f as the dependent variables. The Normal equation was formed and developed using multiple linear regression model computation, which was transformed to matrix and calculated using Gaussian elimination method. The linear regression model of the pipe segment is shown in equation (5).

CONCLUSION

The key cause of this failure as analyzed in this researchwork are corrosion and metallurgical defects mainly along the welded line during the pipe manufacturing process, which probably could not withstand the pipeline operating conditions, therefore resulted to cracks on the pipe structure due to corrosion and then ruptured. Some of the suspected factors that could cause metallurgical defects on the welded portions of pipes are: improper welding parameters such as welding voltage, speed and currents, improper welding flux, Inadequate or wrong filler material. In addition to the above, the Visual and UT flaw detection carried out along the welded line depicts the presence ofcluster porosity, lack of fusion and penetration as weld defects. These inadvertently initiated the cracks on the weld line.

REFERENCES

1. Lyons, W. C., & Plisga, G. J. (2011). *Standard handbook of petroleum and natural gas engineering*. Elsevier.
2. Ghalambor, A., & Economides, M. J. (2000, January). Formation damage abatement: a quarter-century perspective. In *SPE International Symposium on Formation Damage Control*. Society of Petroleum Engineers.
3. Dahlberg, E. P., & Bruno, T. V. (1985). Analysis of Gas Pipeline Failures. *JOM*, *37*(1), 71-73.
4. Eiber, B. (2003). Overview of integrity assessment methods for pipelines. *Washington cities and counties pipeline safety consortium*.
5. Ervin, G. N., & Wetzel, R. G. (2002). Effects of sodium hypochlorite sterilization and dry cold storage on germination of Juncus effusus L. *Wetlands*, *22*(1), 191-195.
6. Buoyan, G., & Ghalambor, A. (2005). Natural gas Engineering Handbook. Gulf professional publishing, Houston Texas.
7. Pandey, M. D. (1998). Probabilistic models for condition assessment of oil and gas pipelines. *Ndt & E International*, *31*(5), 349-358.