Top-of-Line Corrosion Prediction in Offshore Pipelines

By

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Interim Report submitted in partial fulfillment in the
requirement for the
Bachelor of Engineering (Hons)
(Civil Engineering)

MAY 2013

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CIVIL ENGINEERING)

Approved by,

____

(Dr. Zahiraniza Binti Mustaffa)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
May 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the reference and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MOHAMAD MOUNES SADEK

ACKNOWLEDGMENT

First and foremost, I thank and praise God that blesses to finish my task for this project successfully.

I would like to express my utmost appreciation to my supervisor, Dr. Zahiraniza Binti Mustaffa for her guidance, support and encouragement in order to accomplish the tasks. Being his supervisee, it has been a pleasure.

Special thanks are due to the Civil Engineering Department at Universiti Teknologi Petronas that offer facilities to work and study this research. Thanks to Mrs. Aishah for providing support to complete the project.

Lastly, I would give thanks to all postgraduates and friends who assist me to understand extremely in this field of study. Their motivation for learning is greatly appreciated.

ABSTRACT

Pipeline system is the most efficient transportation of oil and gas in offshore industries. Pipeline as most of other materials is subjected to deterioration over time. The oil and gas industries elevated the concern about pipeline corrosion due to itsnegative results on the efficiency of the pipeline system. The corrosion of pipeline most probably will lead to an environmental issues consequent of materials leakage. The materials inside the pipe tend to react with the pipeline wall leading to serious corrosion and potential leakage. The corrosion takes a place all around the pipe wall. Therefore, the corrosion in pipeline is divided to top of line corrosion (TLC) and bottom of line corrosion (BLC) regarding its location. A study on Top of Line Corrosion Prediction is presented in this research in order avoid system leakage and prevent a future pipe failure.

The research result showed a development of corrosion over the years on pipe line. The probability of future corrosion and the range of corrosion in the pipe were studied and prediction equations are modeled. The model show the percentage of corrosion depth in top of line and a comparison between a pipe line historical data was established. The comparison illustrates how the corrosion increases over the years and present its severity. The corrosion orientation model prediction will assist the pipe line inspector to locate the extreme corrosion orientation in the pipe and prevent the further decay.

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CHAPTER 1

INTRODUCTION

1.1 Background

Offshore pipeline has been the most important and efficient oil and gas transportation from the sources of generation. As the oil and gas flow inside the pipe, serious chemical reactions occur between the pipe wall and oil and gas species leading to serious damages in the pipe. This issue starts to be an upsetting matter for the oil and gas industries since the last few years and a vital topic for the scientist which needs to be studied and solved.

Corrosion is the chemical or electrochemical reaction between a material, usually a metal, and its environment that produces deterioration of the material and its properties (1). Corrosion weakens the durability of pipes and in some cases leakage occurs resulting in a serious environmental damaging to the surrounding and economic lost. In the usual pipes (water, drainage, and wastewater pipes) mostly a hydration reaction occurs inside the pipe leading to block the fluid from flowing or decrease the efficiency of the pipe, while in offshore pipes hydration is neglected due to the existence of *glycol* and *methanol* as inhibitors playing a role of preventing the hydrate on pipeline wall (2). Instead corrosion occurs in offshore pipes.

The corrosion occurs when the materials of the pipe tend to reform to its origin form or state by reduction of electron, where iron in pipe react with water leading to reduction of the wall thickness taking place mostly in *top of line* (TLC) due to the condensation of water from gas and in the bottom of the pipe, lateral wall is side effected mostly due to the condensed water falling across due to the gravity force (3).

This research focuses on the carbon dioxide (Co_2) internal corrosions observed at the top of line of the pipe.

1.1.1 Factors of Pipe Line Corrosion

The factors of corrosion are the primer stage for a wider understanding and analyzing of corrosion in pipeline. The scientists draw a conclusion that the most effective way to control corrosion is by minimizing and monitoring the factors of corrosion. The main factors which affect the pipeline corrosion are:

1. Water chemistry
2. Protective scales formation at the steel surface slowing down the corrosion process (4)
3. PH value, when the PH is low the environment in internal pipe line is more to corrosive, vice versa (5)
4. CO_2 partial pressure increasing typically leads to an increase on corrosion (6)
5. The effect of HAc, acid leads to decrease pH value (7)
6. Temperature
7. Flow Velocity increasing can damage the protective scales formed

The dimension and shape of corrosion varies from top to bottom of line. The corrosion rate at the bottom is an order of magnitude higher than the top of the line (7). Typically, it will have an irregular depth profile and extend in irregular pattern in both longitudinal and circumferential directions (8).Forms of corrosion can be classified as crevice, galvanic, intergranular, velocity- or microbial-induced corrosions, or even stress corrosion cracking and selective leaching as schematically(2). Discussion on the dimension of corrosion exceed the scope of this paper, interested readers can refer to the work by(2)for more understanding on the subject matter.

1.2 Problem Statement

The *top of line corrosion* (TLC) has higher proportion of concern than the bottom corrosion due to the complexity of corrosion process and the difficulty of analyzing them as there are various factors affecting the TLC corrosion. Literatures showed that the existing corrosion modeling predictions for the TLC presented are entirely based on an empirical and simulations. Therefore this research proposes a simplified approach to predict the TLC corrosion based on statistical approaches called the Exploratory Data Analysis (EDA) techniques.

1.3 Objectives

This research intends to:

1. Statistically analyze corrosion occurrence along the circumference of an offshore pipeline.
2. Develop prediction models for the top-of-line corrosion in offshore pipeline using the Exploratory Data Analysis (EDA) techniques.
3. Compare historical corrosion development in a pipeline based on the median polish models.

1.4 Scope of Study

Analyzing the top of line corrosion (TLC) using Exploratory Data analysis (EDA) techniques for historical corrosion development in offshore pipelines in Malaysia.

1.5 Relevance of Study

This research will focus mainly on top of line corrosion in pipe line. TLC starts to have more attention in offshore industry due to the complexity of corrosion and the difficulty to maintain the defects. The difficulty lies on how to protect the top side of pipe where injection of inhibitors method is impossible because of low water existence. Hereby, a mathematical model will be developed to predict TLC corrosion mainly in Malaysian offshore pipeline system.

1.6 Feasibility of Study

Gas leakage and piping maintenance is a growing concern for oil and gas companies due to its high cost expenses. The importance of study in real life is to avoid leakage and oil spill from pipeline. Leakage of pipeline materials severely affects the surrounding environment. The model developed will mathematically predict the corrosion in pipelines and foresee failures before occurrence.

CHAPTER 2

LITERATURE REVIEW

This chapter provides a discussion on the literatures of corrosion and its governing factors for better understanding on the subject matter. Majority of the literatures are carried out based on the concern on the factors. A number of experiments established for seeking advance information about the factors impact on pipe and how to inhibit or minimize the effect on the pipe.

2.1 Factors Affecting Corrosion

2.1.1Protective Scales

Protective scales are precipitation of scales in the water drops or the water concentration along the pipe wall. When the precipitation is high enough to create the protective scales it attaches to the wall protecting the pipe wall from corrosion. The most common scale takes its place in Co_2corrosion is *iron carbonate.*

$$Fe^{2+} + CO_3^{2-} \rightarrow FeCO_3$$

The protective scale techniques to low the corrosion is by diffusing the species involved in corrosion process or cover the wall pipe isolating it from the corrosion species.

Protective scales technique of protection is very efficient and appreciated but must be considered that the formation of protective scales requires a special environment and treatment. As mentioned previously the formation of protective scales needs a high precipitation of iron species on the condensed water, but even at high super saturation of iron carbonate the formation is failed if the temperature is low. Conversely, at a high temp usually above 60°C very protective scales can be formed even if the precipitation is low (5).

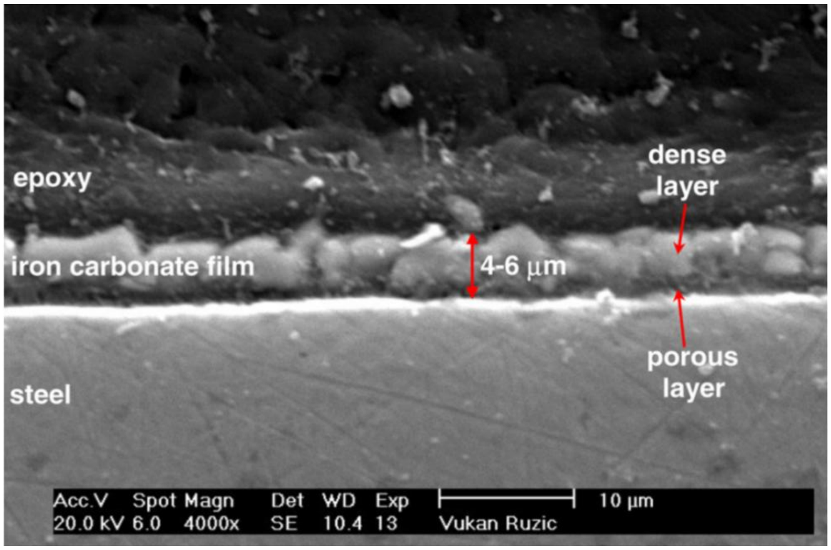

Figure 1. SEM image of a cross section of a steel specimen including an iron carbonate scale. Exposed for 10 h at T=80°C, pH 6.6, PCO_2 ¼0:54 bar,c Fe2þ ¼250 ppm, and *v*= [Adapted from fromNesic and Lee (2003)]

2.1.2 Temperature

The Institute for Corrosion and Multiphase Technology at Ohio University, Athens has build, with a support of the company TOTAL, an experimental flow loop especially designed to study of the TLC. The velocity and Co_2 pressure were fixed and other parameters were changed while the value and rate of corrosion was recorded. The influence of temperature in the experiment was studied at a concentration of HAc of 172 ppm, under a c*ritical condensation rate* and at two different temperatures (50 and 70 °C). The results are presented on Fig.2 and 3. Note that at high temperature the protective scales fail to form if the condensation rate is high (9).

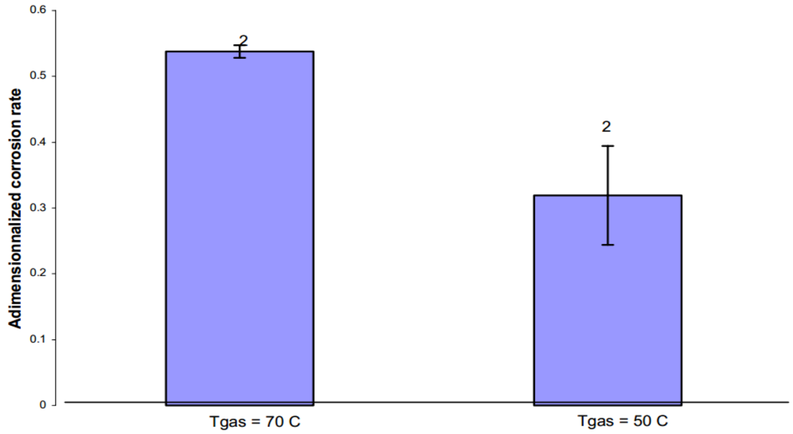

Figure 2. Influnce of temperature on corrosion rate at <u>top of line</u>,gas velovity of 5 m/s, HAc of 171 ppm, critical condensation rate and constant CO_2pressure. [Adapted from Marc et. al (2004)]

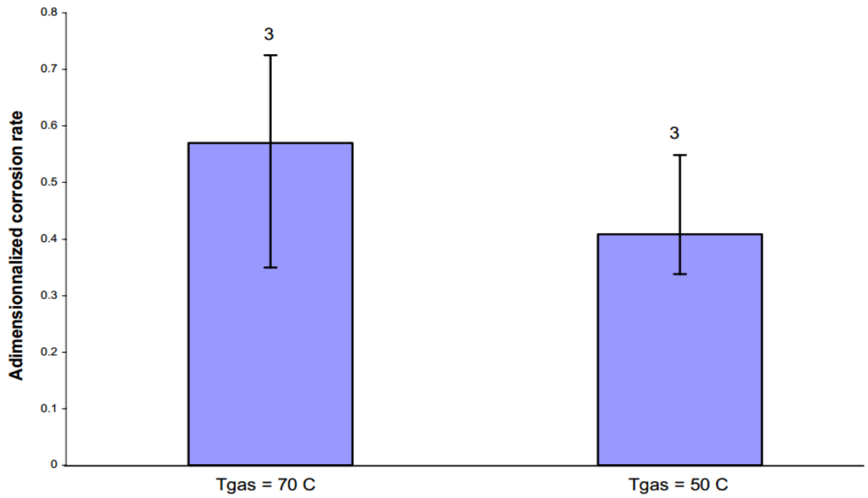

Figure 3. Influence of temperature on corrosion rate at the bottom of line, gas velovity 5 m/s, HAc 171 ppm, critical condensation rate and constant CO_2pressure. [Adapted from Marc et. al (2004)]

2.1.3 Condensation Rate

Condensation is the accumulation of water on the pipe wall due to the differences of temperature between internal and external section of the pipe with the temperature of the gas flowing.

The wet gas condensed on the pipe wall, thus corrosion takes a place. The condensation rate is at highest value at the starting point of the pipe, because the temperature difference is at the highest level.

2.1.3.1Top of Line Corrosion (TLC)

Top of line corrosion (TLC) occurs when a wet gas transport throw the pipe internal wall allowing the wet gas to condense on the internal pipe wall by the force of heat exchange between the outside environment and inside environment temperatures and the effect can be seen in Fig. 4.

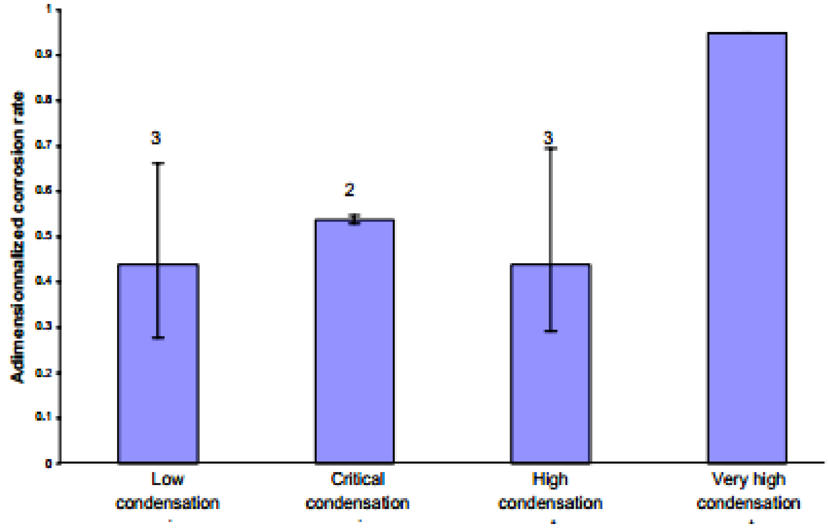

Figure4.Influence of the condensation rate on the corrosion rate at the top of line, gas velovity 5 m/s, HAc 171 ppm,critical condensation rate and constant CO_2 pressure. [Adapted from Marc et. al (2004)]

2.1.3.2Bottom of LineCorrosion (BLC)

Due to the gravity force the water condensed at the top of line drives down through the internal wall to the bottom of line (BLC).

The results in Fig.5 shows that the condensation rate does not influence the corrosion rate at the bottom of line, the reason ilustrates due to the sagnificant amount of water presence on the bottom of line.

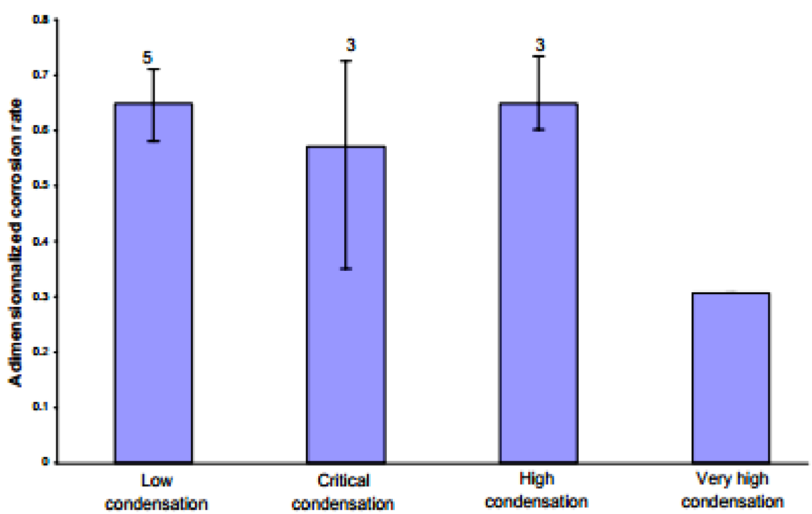

Figure5.Influence of the condensation rate on the corrosion rate at the bottom of line, gas velocity 5 m/s, HAc 171 ppm,critical condensation rate, constant CO_2pressure, temp 70°C.[Adapted from Marc et. al (2004)]

2.2 Models on TLC Corrosion

1.2.1 Condensation Model

A *mechanistic condensation model* is established based on the corrosion growth rate. All the calculation from this model was derived basically from the models developed by Nesic and his research group [(1), (3)].Eventually, a verification of the model established by a comparison between an experimental data and the predicted result from the model.

Fig. 6 shows the test section of the experiment and where the data is collected from. The test section is equipped with a cooling system in order to control the inner temperature of the wall. When a hot wet gas flow through the inner wall, the condensation occurs and then the condensed water is drained downstream by a liquid collector.

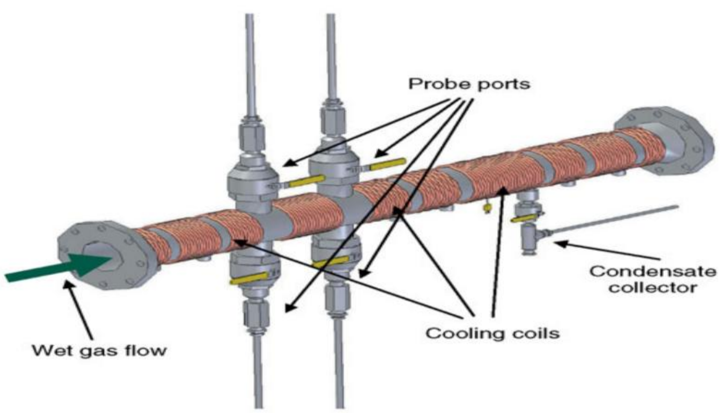

Figure 6. Test section of the experiment
[Adapted from Zhang et. al (2007)]

The comparison between the experiments and model prediction are shown in Fig.7. The model gives good and close results to the experiment work. The experimental results showed close agreement with the predicted models.

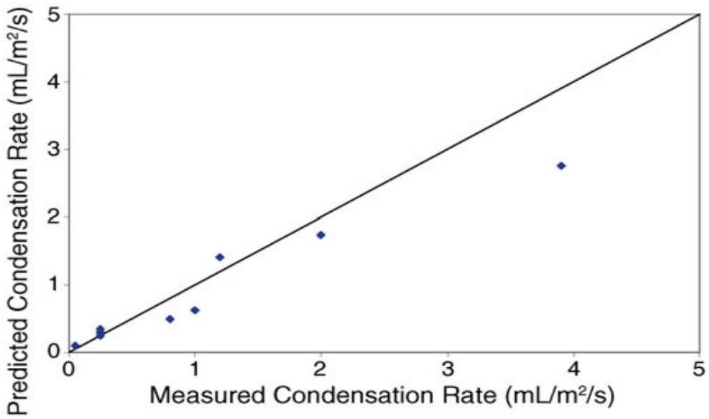

Figure 7. Comparison of measured and predicted condensation rates [Adapted from Zhang et. al (2007)]

2.2.2 Corrosion Model

The *corrosion model* is concerned about the most important parameters and its effect basically on top of line corrosion: gas temperature, CO_2partial pressure, velocity of gas, condensation rate and HAc concentration. All are described by mathematical equationsin the model, which can eventually predict the effect of corrosion on pipe line with time.

The results show a good prediction comparing with the experimental work done for long terms rate prediction. For the short terms (2 days) the model over predicted the corrosion rate, the researcher claims that the discrepancy for short term experiments probably results from the introduced approximation of a 2D problem in a 1D approach (6).

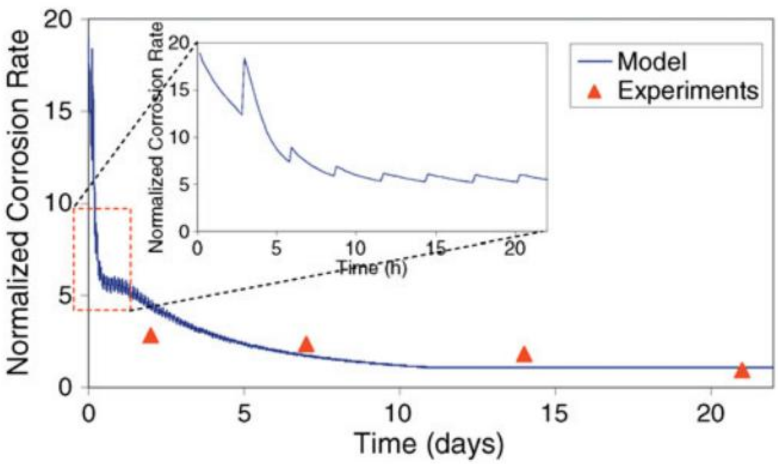

Figure 8. Comparison between the model and long term experiments (T=70°C, V= 5 m/s, P = 3 bar, Pco_2= 2 bar, condensation rate= 0.25 mL/m^2/s) [Adapted from Zhang et. al (2007)]

As a result, Fig.8 shows the comparison between the model and experiments in graph. It can be seen that the corrosion rate at the beginning is very high, this due to the initial condensed water which is very corrosive. The corrosion starts to reduce with time; this is because of protective scales formation on metal surface. Over time, the scales becomes denser, thus the corrosion decrease dramatically and remains at very low state in long terms.

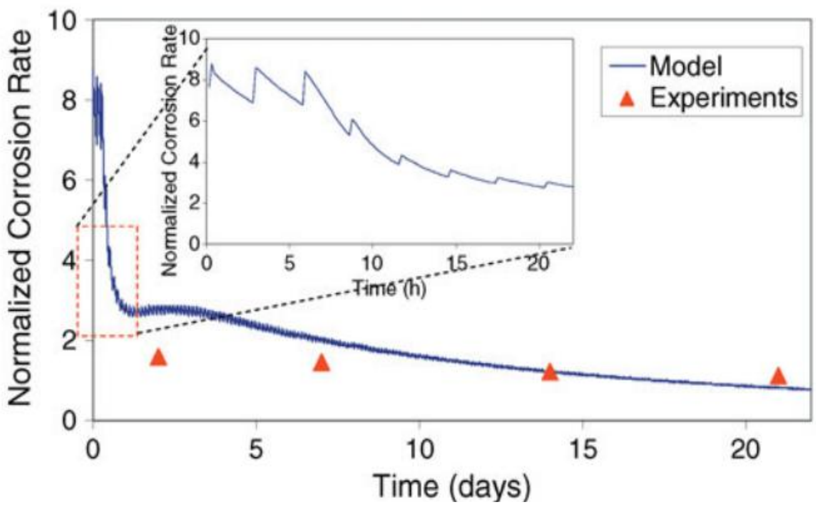

Figure 9. Comparison between the model and long term experiment (T=40°C, V= 5 m/s, P = 3 bar, Pco_2= 2 bar, Condensation rate= 0.2 mL/m^2/s) [Adapted from Zhang et. al (2007)]

Fig. 9 explains that the formation of scales still retards the corrosion even when the *temperature is 40°C* which is consider low. The corrosion starts as very corrosive then gradually decreased with the formation of scales. At the starting point the pH shows a low value, which is not prober for the formation of scales. As the corrosion proceed and concentration of species increase in the droplets the pH tends to increase in value, thus the scales form.

CHAPTER 3

METHODOLOGY

3.1 Research Concept

The research intends to generate a model from sets of data collected from pipelines in Malaysia. The set of data is analyzed statically by using a statistical technique called the *Exploratory Data Analysis* (EDA). The EDA analysis will be carried out through simulation using a Minitab software. The data collected represents internal corrosions along the pipeline which located on the pipe wall.

In order to simplify the data input into the analysis, the pipe is divided *into o`clock orientation*, measured from the cross section of the pipe, as shown in
Fig. 10.

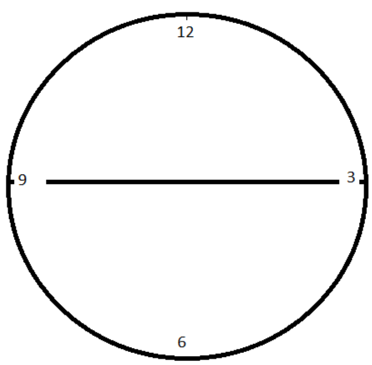

Figure 10.Corrosions to be divided based on *o'clock orientation* of the pipe

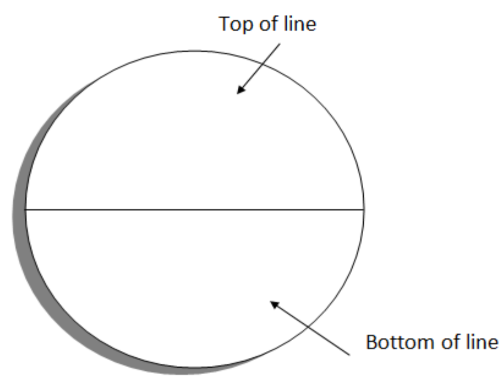

Figure11. Cross section of pipe divided into *top of line* (TLC) and *bottom of line* (BLC) corrosions

Hereby, the defects occurred in the pipe wall will be statistically placed based on its location, as shown in Fig. 11. The expected outcome of the software is a model equation developed to predict the top of line corrosion (TLC) in offshore pipelines (*i.e.* Objective 2). Lastly, the model is used to compare historical pipeline corrosion in Malaysia (*i.e.* Objective 3).

3.2 EDA

(EDA) is an approach to analyzing data sets to summarize their main characteristics, often with visual methods. EDA is for seeing what the data can tell us beyond the formal modeling or hypothesis testing task.

In this research EDA technique is used for a statically analyzing the data related to pipeline. The implementation of this technique in this research is estimation the corrosion statically and predicts the probability of future corrosion.

3.2.1 Box plot

In descriptive statistics, a box plot a convenient way of graphically depicting groups of numerical data through their quartiles. Box plots may also have lines extending vertically from the boxes (whiskers) indicating variability outside the upper and lower quartiles. Outliers may be plotted as individual points.

Box plots display differences between populations without making any assumptions of the underlying statistical distribution. The spacing between the different parts of the box help indicate the degree of dispersion (spread) and skeness in the data, and identify outliers.

3.2.2 Stem and Leaf

A stem-and-leaf display is a device for presenting quantitative data in a graphical format, similar to a histogram, to assist in visualizing the shape of a distribution. They evolved from Arthur Bowley's work in the early 1900s, and are useful tools in exploratory data analysis. Stem-and-leaf displays retain the original data to at least two significant digits, and put the data in order, thereby easing the move to order-based inference and non-parametric statistics. (10)

3.2.3 Median Polish

The median polish is an exploratory data analysis procedure proposed by the statistician John Tukey. Median Polish a common technique of EDA that uses the median to determine the characteristics of data. In this research, median polish is used to predict the corrosion depth and illustrate the range of predicted corrosion in pipe line.

CHAPTER 4

RESULT AND DISCUSSION

Result obtained from the EDA Minitab v.16 software is more detailed in this chapter. The pipeline is analyzed based on historical corrosion by three different years, 2004, 2007 and 2011. It was found that the number of corrosion plots has increased by years and the pipeline defects rate has also risen to a higher level. The tables below present a comparison between the pipelines in both top of line and bottom of line data.

Table 1, Top of line (IP Data 2004)

	Depth %	Length (mm)
Number	54	54.0
Mean	1.3	37.2
Median	1.0	37.0
Standard Dev	1.3	11.3
Min	1.0	20.0
Max	8.0	65.0

Table 2, Bottom of Line (IP Data 2004)

	Depth %	Length (mm)
Number	30	30.0
Mean	1.1	39.0
Median	1.0	37.0
Standard Dev	0.3	11.9
Min	1.0	21.0
Max	2.0	72.0

Table 3, Top of line (IP Data 2007)

	Depth %	Length (mm)	Width (mm)
Number	332.0	332.0	332.0
Mean	7.6	32.7	33.8
Median	7.0	29.0	28.0
Standard Dev	4.7	15.0	24.2
Min	1.0	9.0	5.0
Max	29.0	174.0	214.0

Table 4, Bottom of Line (IP Data 2007)

	Depth %	Length (mm)	Width (mm)
Number	223.0	223.0	223.0
Mean	7.3	32.6	41.3
Median	6.0	26.0	29.0
Standard Dev	4.7	32.3	43.0
Min	1.0	9.0	9.0
Max	21.0	284.0	317.0

Table 5, Top of line (IP Data 2011)

	Depth %	Length (mm)	Width (mm)
Number	541.0	541.0	541.0
Mean	4.0	37.1	35.0
Median	4.0	32.0	30.0
Standard Dev	1.5	23.3	23.3
Min	1.0	0.0	0.0
Max	13.0	312.0	245.0

Table 6, Bottom of Line (IP Data 2011)

	Depth %	Length (mm)	Width (mm)
Number	451.0	451.0	451.0
Mean	3.8	34.8	36.1
Median	4.0	27.0	26.0
Standard Dev	1.5	24.5	34.9
Min	1.0	1.0	1.0
Max	13.0	255.0	283.0

The tables classify the data in several categories. The standard deviation shows how much variation or dispersion exists from the average mean. Minimum and maximum represent the lowest and highest readings respectively.

The tables clearly indicate how the corrosion on TLC is higher in value than BLC as it shown in number classification. In terms of corrosion severity, it is clearly illustrative in the tables how TLC higher than BLC in comparison. The result shown demonstrates why (TLC) has higher proportion of concern than the bottom corrosion.

4.1 Corrosion Characteristics Based on Different Region

4.1.1 Stem and Leaf for 2007 Data

A stem and leaf display is a presenting for quantitative data in a graphical format, similar to a histogram, to assist in visualizing the shape of a distribution(11). The Stem and Leaf display presents a graphical picture of the distribution of the data values. It displays whether the data is symmetrical, left skewed, biomal or multimodal. It also reveals whether or not there are large gaps in the data set. The stem and leaf contains more information in the sense that the actual data values are displayed.Fig.13 presents the stem and leaf data for top of line 2007 pipeline corrosion

```
Stem-and-leaf of Top of line  N  = 332
Leaf Unit = 1.0


 19   0  1111111111111111111
 58   0  222222222222222333333333333333333333333
124   0  44444444444444444444444455555555555555555555555555555555555555555+
(74)  0  66666666666666666666666666666666666667777777777777777777777777777+
134   0  888888888888888888888999999999999999999
 95   1  00000000000000000111111111111
 66   1  222222222222222333333333333333
 36   1  4444444444555555
 20   1  666667777
 11   1  8889
 7    2  01
```

Fig.12 stem and leaf display for 2007 top of line

The median positioned within the result forth row (leave), which indicates in parenthesis (). The median is an important concept in EDA, in stem and leaf the median enter into the construction of the display. The figure shows a skewed data mostly to right, hereby, the corrosion distribution is dominated in a limited area of the pipe.

4.1.2Letter Value Display

Fig.14 shows a Letter value display for TLC 2007. The figure gives a quick summary of the data set. The figure illustrate that the data is skewed to the right as the mid values are increasing. Mid values indicates that the data is approximately symmetrical. From the display below, the median impact factor is 7.00. The minimum impact factor is 1.00 while the maximum is 29.00 and the range is 28.00.

The letter (H) represents the word hinge. The lower hinge spread is an important parameter to be used in Median Polish modeling.

```
Depth  Lower   Upper     Mid  Spread
N=    332
M   166.5  7.000   7.000   7.000
H    83.5  5.000  10.000   7.500   5.000
E    42.0  3.000  13.000   8.000  10.000
D    21.5  2.000  15.000   8.500  13.000
C    11.0  1.000  18.000   9.500  17.000
B     6.0  1.000  21.000  11.000  20.000
A     3.5  1.000  25.500  13.250  24.500
Z     2.0  1.000  27.000  14.000  26.000
1  1.000  29.000  15.000  28.000
```

Fig.13 Letter Value display for 2007 Top of Line

4.1.3 Box Plot Display

The box plots are useful graphical display of a given data set. The box plot reveals the range of the data, whether or not the batch is symmetrical and also draws attention to the presence of extreme observations (11).

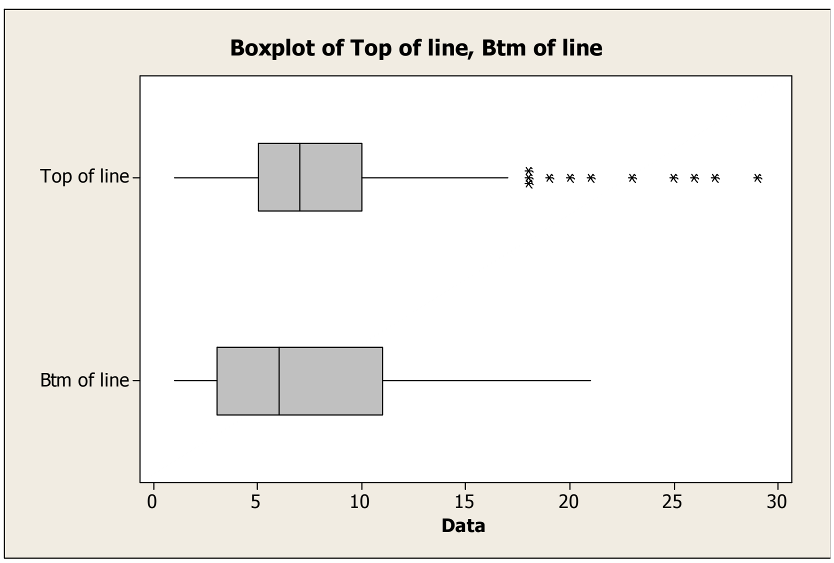

Fig. 14 Box plot display for TLC and BLC for 2007 data

It is clear from the figure above how the data skewed to the right as the median line located in the left half of the box. The outliers presence in TLC higher than BLC which can be taken as another evidence of the TLC corrosion proportion. The outliers in top of line plot represent an extreme value of corrosion depth.

4.1.4 O'clock Orientation Corrosion

The intention of this analysis is to expand the comprehension about pipe line corrosion by a different cross section view. The o`clock orientation provide a variance corrosion in each orientation (recall methodology).

Fig.15 shows a box plot display for each o`clock orientation. On examining the data, it clearly seen that the corrosion distribution and depth are uniformly occur in each orientation. The box plot display explains how the corrosion depth varied in each location. The result data outliers are more skewed to right. Orientation 6, 10 and 11 experienced the higher values as it seen from the figure, the expectation of corrosion on those orientations is high and proper attention should be given to those orientations. The outliers seen in orientation 11 represent the extreme values of corrosion. Fig.16, shows the distribution of corrosion data using excel sheet. It clearly noted hoe is the distribution display of box plot is better in terms of well ranging and less scattering.

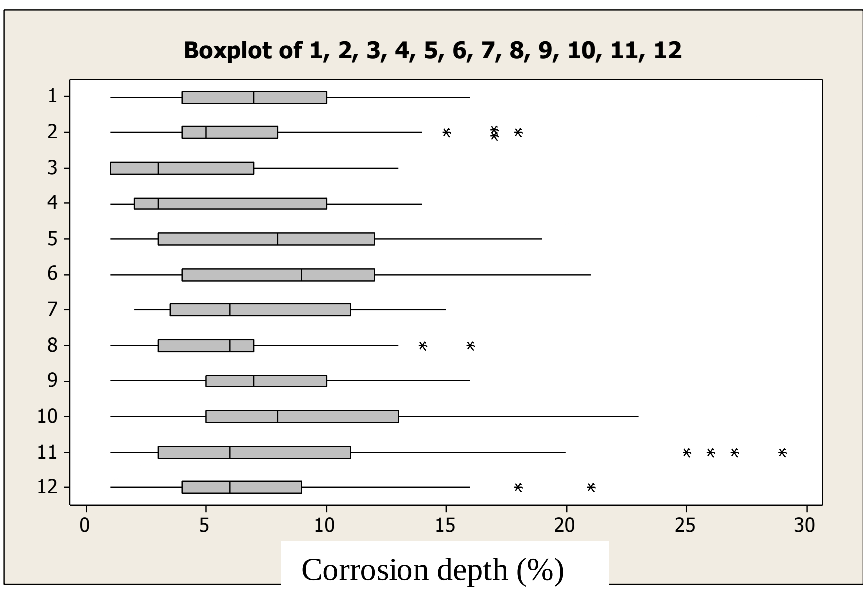

Fig.15, Orientation Box Plot Display

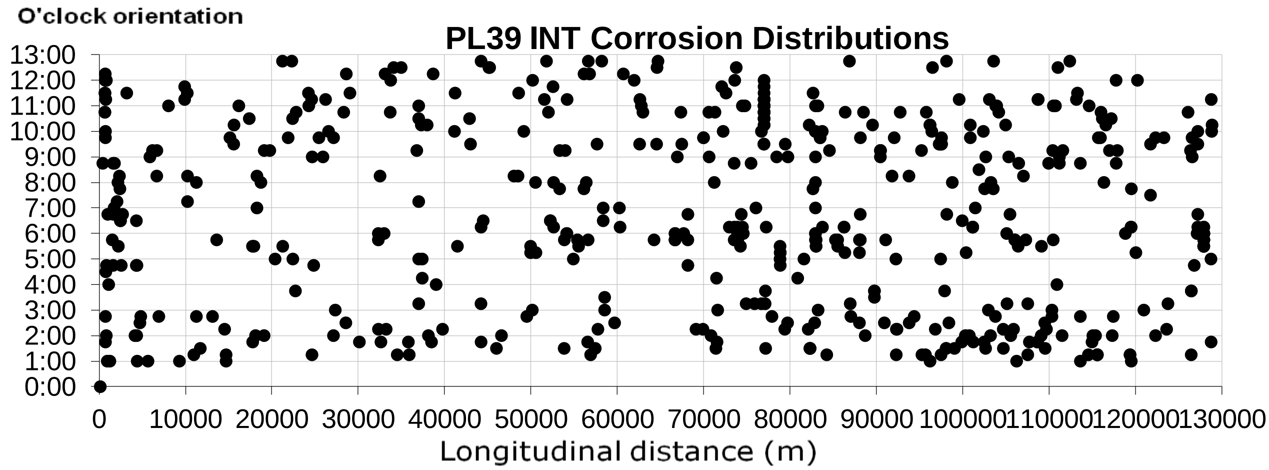

Fig.16 distribution of corrosion data using excel sheet

4.2 Top of Line Corrosion Modeling

4.2.1 Historical Corrosion Development

In this part of the research, a historical comparison between all the top of line data that was compiled from the pipe line. Fig 17 and Fig18 summarize the data set for 2004 TLC and 2011 TLC respectively comparing with TLC 2007 (recall fig 14)

	Depth	Lower	Upper	Mid	Spread
N=	54				
M	27.5	1.000	1.000	1.000	
H	14.0	1.000	1.000	1.000	0.000
E	7.5	1.000	1.000	1.000	0.000
D	4.0	1.000	2.000	1.500	1.000
C	2.5	1.000	5.000	3.000	4.000
B	1.5	1.000	8.000	4.500	7.000
	1	1.000	8.000	4.500	7.000

Fig.17, 2004 Top of Line Letter Value

	Depth	Lower	Upper	Mid	Spread
N=	541				
M	271.0	4.000	4.000	4.000	
H	136.0	3.000	5.000	4.000	2.000
E	68.5	3.000	5.000	4.000	2.000
D	34.5	2.000	6.000	4.000	4.000
C	17.5	2.000	7.000	4.500	5.000
B	9.0	1.000	8.000	4.500	7.000
A	5.0	1.000	9.000	5.000	8.000
Z	3.0	1.000	12.000	6.500	11.000
Y	2.0	1.000	13.000	7.000	12.000
	1	1.000	13.000	7.000	12.000

Fig.18, 2011 Top of Line Letter Value

The figures clearly show how the data set increased over the years. Moreover, the depth of data (corrosion) significantly increased as well. Median, upper and lower reading also increased. The plots show an increase in standard deviation

4.2.2 Box Plot Comparison

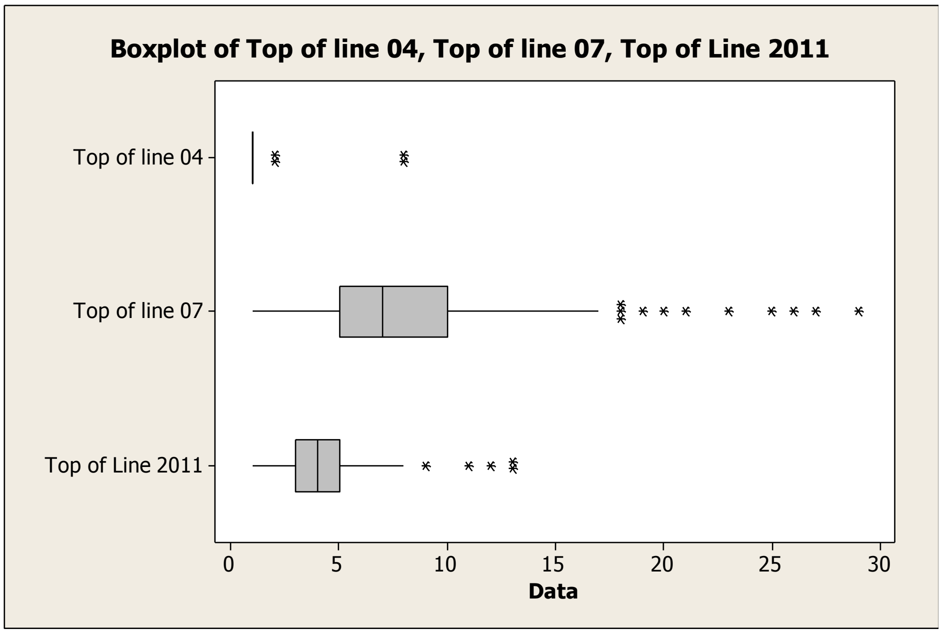

Fig.19 box of plot data for historical TLC

When comparing the results obtained in 2004 with the ones obtained in 2007, it shows a noticeable difference in the amount of data obtained as 2007 was more, which is logical to have such results for a pipeline in time variable.

Another comparison between top of line in 2007 and 2011 shows a different act which can lead to the observation of an error during obtaining the data in 2011 which lead to the discrepancy of data , this error is can mainly be referred to the pigging tool, as the data itself may have been beyond the scope of research.

4.2.3 Stem and Leaf Comparison

```
Stem-and-leaf of Top of line 04  N  = 54
Leaf Unit = 0.10


(50)  1  00000000000000000000000000000000000000000000000000
 4    2  00
 2    3
 2    4
 2    5
 2    6
 2    7
 2    8  00
```

Fig.20, 2004 Stem and Leaf Top of Line

```
Stem-and-leaf of Top of line  N  = 332
Leaf Unit = 1.0


 19   0  1111111111111111111
 58   0  222222222222222223333333333333333333333
124  0  44444444444444444444444455555555555555555555555555555555555555555+
(74)  0  66666666666666666666666666666666666677777777777777777777777777777+
134  0  888888888888888889999999999999999999999
 95   1  00000000000000000001111111111
 66   1  222222222222222333333333333333
 36   1  4444444444555555
 20   1  666667777
 11   1  8889
 7    2  01
```

Fig.21, 2007 Stem and Leaf Top of Line

```
Stem-and-leaf of Top of Line 2011  N  = 541
Leaf Unit = 0.10


 13    1   0000000000000
 62    2   0000000000000000000000000000000000000000000000000
 193   3   00000000000000000000000000000000000000000000000000000000000000000+
(165)  4   00000000000000000000000000000000000000000000000000000000000000000+
 183   5   00000000000000000000000000000000000000000000000000000000000000000+
 63    6   00000000000000000000000000000000000000000000
 19    7   0000000000
 9     8   0000
 5     9   0
 4     10
 4     11  0
 3     12  0
 2     13  00
```

Fig.22, 2011 Stem and Leaf Top of Line

The figures above illustrate how the corrosion increases over the years. In stem and leaf display the number of leaves contains the median is indicated in parenthesis () on a column to the left of the stem column. In figures above the median position is mostly skewed to the lift (top), this indicates that the distribution of corrosion in pipe is concentrated mostly within a limited area of the pipe section

4.2.2 Median Polish Model

In this section a median polish technique is used in order to generate a corrosion model. The developed model is suitable to develop a model prediction for all top of line corrosion with respect to its orientation. A comparison between the historical Top of Line corrosion will be established.

The model equation subedit as

$$d_{ij} = \mu + \tau_j \qquad (1)$$

Where, *i= 1,2,3,……..,*n_j

j= 1,2,3,…..,12 o`clock orientations,

d_j *= Internal corrosion depth (%),*

μ *= Overall effect*

τ_j *= Orientation effect,*

n_j*= the sample size of the* j^{th} *orientation.*

The variables of the model equation were measured by using EDA Minitab v.16. The variables measurement was found to be,

$\mu = 4$

τ_{2004}= -3

$\tau_{2007} = 3$

$\tau_{2011} = 0$

The fitting model proposed by Minitab software is

$$d_{ij} = \mu + \tau_j \pm (1.5 * H.spr) \quad (2)$$

The H-spread value (H.spr) found as 3% of the proposed model. Therefore, the prediction interval for TLC is,

a) For 2004 Top of Line,

$$d_{2004} = 4 - 3 \pm (1.5 * 3) = 0\% - 5.5\%$$

b) For 2007 Top of Line,

$$d_{2007} = 4 + 3 \pm (1.5 * 3) = 2.5\% - 11.5\%$$

c) For 2011 Top of line,

$$d_{2011} = 4 + 0 \pm (1.5 * 3) = 0\% - 7.5\%$$

The result above illustrates how much the top of line is likely to have corrosion depth in interval value.

A prediction Table is developed based on the model as,

Top of Line	Predicted Value, Eq(1)	Prediction Interval, Equ (2)
2004	1%	0% - 5.5%
2007	7%	2.5% - 11.5%
2011	4%	0% - 8.5%

Table 7, Prediction table

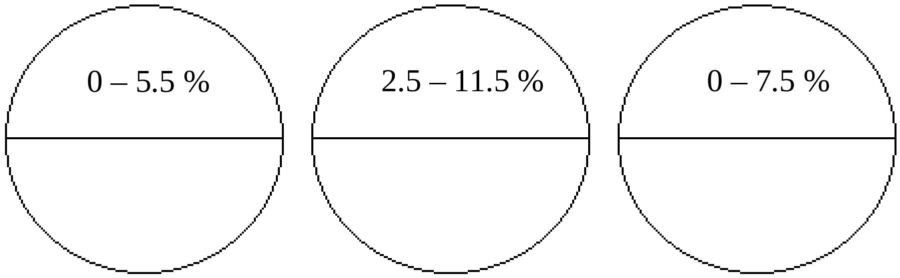

Figure 23, cross section of predicted value

In figure 23 a cross section of predicted pipe corrosion is plotted. It is noticeable from the plot how the predicted value of 2011 is less than 2007 which conflict with idea of corrosion increasing over the time. The error is referred to the pigging tool as the percentage of it accuracy is less than 2007. Referring to the industry where the data was collected, the pigging tool which is responsible for collecting the data of the pipe experienced a defect during its journey through the pipe line.

CONCLUSIONS AND RECOMMENDATION

Understanding internal corrosions in oil and gas pipelines has come a long way over the past few years. The influence of many factors and parameters on pipelines corrosion has been covered in this research. Controlling and monitoring the corrosion factors is found to be the most efficient way to minimize the risk of corrosion especially on top of line.

A corrosion prediction equation was established in this research to predict the corrosion on top of line. The historical statically comparison proofed the authenticity of the literature review. The model present the most effected orientation by corrosion and alert the inspectors to keep an eye on it to prevent further decay. The median polish equation will assist the oil and gas industry to predict the corrosion and preserve the pipe line for longest period.

Recommendation:

Following points are recommended for future work

- Accuracy
- Eccentric
- Time interval
- Historical data

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