COMPARATIVE STUDY OF SEVERAL STATISTICAL MODELS IN MONITORING THE PIPING CONDITIONS IN PETROLEUM PROCESS

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MECHANICAL ENGINEERING

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Comparative Study of Several Statistical Models in Monitoring the Piping Condition in Petroleum Process

by

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CERTIFICATION OF APPROVAL

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Approved by,

____

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Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

MAY 2014

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 references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons

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MUHAMAD SYAMIM BIN HASBULLAH HALMI

ABSTRACT

In preparation to encounter metal thinning phenomenon on the piping spools in petroleum process, a simulation statistical model which apply the best approach in determining the corrosion rate and the remaining life has been establish. Ultrasonic thickness spot measurement is the most reliable way to inspect the deterioration condition of the piping spools. The indicated data from the ultrasonic thickness spot measurement is always affected the evaluation of the corrosion rate of the piping condition. Hence, to experience a better view of the corrosion rate at the piping spools, this study is being carried to aside the unknown effect on the varying data thickness measurement and thus, a conservative corrosion rate can be determine. The conventional and statistical approach has been practise with case study 1 and case study 2 and the result has been assessed. It is proposed that statistical methodology more conservative than the conventional methodology with proven result that has been established as the statistical methodology offer an extra precaution in corrosion concern.

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CHAPTER 1

INTRODUCTION

1. INTRODUCTION

The author will give explanations about this project background, problem statement objectives, scope of study, relevancy, feasibility and the validity of the project.

1.1 Background

One of the most main components of the facilities in the industrialized world is the rapid network of the pipelines and process piping which literally applied millions of miles. The term \`piping system\` is refers to the web or interconnected of piping subject to the same set or sets of design condition. The term \`piping\` generally is assemblies of piping components used to transport, distribute, mix, separate, discharge, meter, control or snub fluid flows and act as pipe-supporting elements but does not include support structure (Becht, 2004). This piping involving the process and the pipelines is commonly manufactured by steel and cast iron. Piping is consisted a mechanical elements which play mechanical system such as joining, assembly and supporting with specific mechanical components (Becht, 2004). The most common approach of joining each segment in pipe individually is by welding or soldering depend on the characteristics of the metal assigned.

Pipelines and process piping act as transportation is considered the most reliable and safest medium across the manufacturing facilities and across countries. However, failures do happen given the complex and extensive network of pipelines and piping spools. The potential impact of this failure is spectacular and can lead to extensive property damage and loss of life. It is important to study and have a better knowledge to investigate this failure occasion which applying an engineering and scientific disciplines. With the broad scale of skill and knowledge, this failure can be hindered by investigating and introduced a better approach of methodology in monitoring the pipeline and piping system.

1.2 Problem Statement

Generally, the process piping which is the to transport the chemical materials and substances through a specific process subjected with a certain value of pressure always a major role when highlighting the safety aspect of the chemical plants and refineries. But, when the case is subjected to the complex structure of the piping system, it is difficult to determine the thickness on the specific location. Hence, the corrosion rate cannot be assessed. Multiple approaches have been introduced to cooperate with the corrosion rate. Integrity, reliable, feasible and conservative approach need to be selected to encounter the problem stated.

1.3 Objectives

- To assess the corrosion rate based on the conventional methodology and statistical methodology.
- To evaluate and recommend the method between conventional methodology and statistical methodology.
- To apply the concept of conventional methodology and statistical methodology with case study.

1.4 Scope of Study

The pipelines and piping spools are constructed and maintained in accordance of applicable industry standard which is ASME B31. This research also apply API standard when inspector undergoing the inspection process. Other parameters such as temperature, pressure and flow rate of the substance is assumed constant throughout the research. Moreover, this project focused on the thickness measurement data and the location of the thickness measured. Furthermore, on this research, one of the approaches which are statistical methodology approach assumed that the piping system suffered from general corrosion under normal conditions. It is also assumed that there is no localised corrosion defects occur at the inside and outside surfaces of the pipe spools and no visual defects outside surface of the pump which need to repair (Chi Hui Chien, 2008).

1.5 Relevancy of the project

The project is relevance to carry out due to the explanations and presentations about the most conservative approach for the inspector to monitor the piping condition. Moreover, the corrosion rate is being discussed and has provides a tool that helps in estimating the potential deteriorate condition beside waive the uncertainties of the thickness measurement data.

1.6 Feasibility of the project.

The author of this project believes this project can be accomplished its objective within the timeframe given. The calculation detail and information of this project mostly has been taught in the previous syllabus in Mechanical Course. As an example, one of the approaches to monitor the piping condition in the petroleum process is the statistical method which mainly about the concept of mathematical statistic and probability calculation and formula. On the other hand, for conventional methodology, the syllabus such as Engineering Material also has been taught in the course which is much related to the life cycle, thickness measurement and corrosion rate has been discussed briefly during the time.

1.7 Validity of the result.

The author has practically calculated and assessed the conventional methodology and statistical methodology. The case study is valid as it’s obeyed and follows the API standard. The result has been calculated by the author.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2. LITERATURE REVIEW AND THEORY

During this section, the author will discuss about the past research that is relevant to this project by cross-referencing and critical analysis. Furthermore, the author will highlight about the theory adopted and the case studies that being applied throughout this project.

2.1 Literature Review

According to several researches, the chosen publication in assessing the corrosion defects in a process piping mostly is American Society of Mechanical Engineering (ASME) code ASME-B31G. Generally, ASME-B31G is a method that assesses the loss defects due to corrosion of metal by evaluating the remaining strength of externally corroded pipe subjected to internal pressure loading (Dewint, 2011). This method has claimed to be conservative than the other testing method which is Test Vessels, Material Property Testing and Burst Testing that use the actual burst pressure value that will cause the pipe to fail (Lefevre, 2004). But, according to (Coulson, 1990a) it is proven that the assessment of the ASME B31G is over-conservative to the piping process. This is because the high model of uncertainty from lacking of actual values from database such as the real corrosion defects, sharp defects, and complex shaped defects. Hence, several modifications from the equation have been proposed to minimise the conservatism of ASME B31G methods (Marley, 2001). With respect to previous statement, Kiefner and Veith (1990) have provided the approach which has proposed some modifications such as two-term approximation for the Folias factor used in the B31G criteria. It improves the accuracy of the piping spool assessment.

One of the methodologies to determine the corrosion defects is conventional methodology. Based on the Chi-Hui Chien research on 2008, the conventional methodology approach is said to be the easiest Non-Destructive (NDT) method when performing the piping inspection. But, the inspectors is always confuse in selecting the thickness measure subjected to multi-thickness location chosen to calculate the corrosion rate. Practically, to acquire the thickness measurement location located in the same point between two measurements is nearly impossible. Hence, the estimation of the corrosion rate consists of large area of uncertainty. Therefore, the statistical methodology is introduced. Statistical methodology is the more conservative evaluation about the corrosion rates of the piping spools which the uncertainties of the estimated corrosion rates can be determine by selecting a suitable confidence level of the measured thickness data.

By studying the statistical methodology method for monitoring the piping condition in petroleum process, the illustration of the deteriorate condition is easily shown by plotting the histogram based on the estimated corrosion rate data. The deterioration condition of piping is crucial in maintaining the piping condition. The deteriorate phenomenon occur when metal thinning occur due to the corrosion rate will lead to residual stresses and in-service corrosion. These factors will affect the leakage and thus increasing the failure probability (A.Amirat, 2006). To encounter this scenario, reliability analysis is introduced to assess the effect taken and to manage the lifetime efficiently. Furthermore, deficiencies in design such as manufacturing defects, fabricate defects, and service defects also will cause the failures in piping system to malfunction (Thielsch, 1993). Hence, a proper inspection and maintenance is essential for ensuring the continuous operation. Risk Based Inspection approach is used to calculate the risk using the piping failure probability analysis and First Order Reliability Method (FORM) (Ainul Akmar Mokhtar, 2009).

2.1.1 Cross-referencing / Chronology title establishment.

Table 1: Cross reference

No.	Research Title/ Book	Scope of Study	Limitation(s) of Study	Comment(s)
1	ASME B31G(1990)	Remaining Strength of the Corroded Pipeline	1) Only for ASME Standard 2) Defects only in the body of pipeline 3) Cannot estimate the remaining strength in complex structure. 4) Less range of parameter design	Over-conservative: 1) Expression for flow stress 2) Approximation used in Folias Factor (Kiefner and Veith , 1990) 3) Limitation to long areas of corrosion (Thomas J. O'Grady II ,1992)
2	Modified B31G Provide two-term approximation for Folias Factor (Kiefner and Veith,1994)	Accuracy of the assessment corroded piping spool	Only limited to the range of material and dimension	Propose BG technology to perform large number of burst test to determine the uncertainty (Battle et al, 1997)
3	ASME B31G(2002)	Remaining Strength of the Corroded Pipeline	1) Only for ASME Standard 2) Defects only in the body of pipeline 3) Cannot estimate the remaining strength in complex structure.	Still accepted by plant nowadays (Chi-Hui Chien and Chun-Hung Chen ,2008)
4	Assessment of Corroded Pipelines (O.H Bjerney ,2001)	Determine the Real Corrosion Defect Measurement of Corroded Pipeline	Lacking of actual values	The test result are not publicly available hence cannot verify the result by others.
5	Applying statistical methodology to monitor the piping conditions in petroleum process (Chi-Hui Chien and Chun-Hung Chen ,2008)	Handle the uncertainties of variation of thickness measurement location	Conventional and Statistical Methodology approach	Statistical Methodology is selected.

2.2 Theory

2.2.1 Conventional Methodology

Conventional methodology approach has been identified as the easiest Non Destructive (NDT) approach for the piping inspection. Before obtaining the data from ultrasonic survey in the piping spools, based on the conventional methodology, the inspector needs to re-organise the thickness measurement locations at the possible deterioration takes place such as joints. Then, the evaluation of corrosion rate and remaining life is conducted. Straight pipe is chosen as an example to evaluate the corrosion rate and remaining life by using the equation provided by ASME B31.3 (2002) and API 570 (1997):

$$t_{required} = \frac{PD}{2SE} \dots\dots\dots\dots\dots\dots\dots\dots (1)$$

$$corrosion\ rate = \frac{t_{previous} - t_{current}}{time\ (years) between\ t_{previous}\ and\ t_{current}} \dots\dots\dots\dots\dots\dots\dots\dots (2)$$

$$remaining\ life = \frac{t_{current} - t_{required}}{corrosion\ rate} \dots\dots\dots\dots\dots\dots\dots\dots\dots. (3)$$

Based on equation (1), $t_{required}$ is the required thickness for the component to be functional before corrosion allowance and the manufacture tolerance were considered; P is the internal design gauge pressure of the pressure component; D is the outside diameter of the pressure component as listed in the table standard, specification or as measured during fabrication; S is the allowable stress value for the pressure component of material fabricated and E is the quality factor. For equation (2) and (3), the $t_{previous}$ is the thickness measurement at the same location of $t_{current}$ in millimetres.

In real world application, the inspector always has a difficult in choosing the $t_{previous}$ and $t_{current}$ especially in complex-thickness location chosen to calculate the corrosion rate and remaining life of the pipe. To overcome this incident, the inspectors preferably choose the average reading of the thickness measurement. Hence, the outcome of the result always deviate from actual result and the result even are unreasonable. Based on the C.H. Chien and C. H. Chen in 2008, the probability of inspecting each thickness measurement location located exactly in the same point between two measurements is nearly impossible. In addition, the authors claimed that the inspector cannot always get the representative thickness value between the previous and the last measurement. In one other case, the $t_{current}$ may be higher than the$t_{previous}$. Hence, the result is unreasonable.

2.2.2 Statistical methodology

Commonly, the fabrication material of carbon steel such as ASTM A53,A 106, A381 and API-5L to be used in the piping system which applied in chemical plants and refinery. The solely purpose of this piping is to convey the chemical materials in petroleum process and is designed to avoid any severe corrosion condition. It can be considered as the piping system is suffered from general corrosion under normal operating conditions. Furthermore, it is assumed that there is no localised damage on the inside and outside surface of the piping spools. Under these assumptions, the distribution of the thickness data can be considered as normal distribution. Therefore, statistical methodology is adopted.

By obtaining the actual variance of the thickness spools,σ^2, it is unachievable to obtain the actual inspection work which is $V(\bar{X}) = \frac{\sigma^2}{n}$, where n is the number of measurement. However, by assuming the piping spools is normally distributed, the statistical methodology can be replaced by $S^2(\bar{X}) = \frac{\hat{S}^2}{n}$, which can be calculated from measured thickness data. The acceptable confidence level is measured thickness data for the plant owner is α, the possible mean value can be approached by using Student`s t distribution based on the confidence level α, which expressed in equation below (Yan,2002):

$$P[-t_{(1-\left(\frac{\alpha}{2}\right),(n-1)} \leq \frac{\bar{X}-\mu}{\hat{S}/\sqrt{n}} \leq t_{(1-\left(\frac{\alpha}{2}\right),(n-1)}] = 1-\alpha \ldots\ldots\ldots..(5)$$

$$\hat{S} = \sqrt{\frac{(R_1-\bar{X})^2+(R_2-\bar{X})^2+(R_3-\bar{X})^2+(R_4-\bar{X})^2+\cdots+(R_n-\bar{X})^2}{n-1}}..(6)$$

Where,

$\bar{X}$= is the mean value of the measured thickness data

n= the quantities of the measured ultrasonic thickness readings

μ= mean value of the possible actual piping thickness

R_n = the readings of ultrasonic thickness measurement

$t_{(1-\left(\frac{\alpha}{2}\right),(n-1)}$ = Student`s t distribution value with the probability of $1-\alpha$

$\hat{S}$ = root mean square value of the measured thickness data.

By rearranging the equation 6 and substitution with other equation, the final expression for possible corrosion rate of piping spools of statistical methodology is as follows:

$$\frac{\left(\bar{X}_{previous} - \bar{X}_{current}\right) - t_{\left(1-\left(\frac{\alpha}{2}\right),(V)\right)} S_p \left(\left(\frac{1}{n_{previous}}\right) + \left(\frac{1}{n_{current}}\right)\right)^2}{f}$$

$$\leq \frac{\mu_{previous} - \mu_{current}}{f}$$

$$\leq \frac{\left(\bar{X}_{previous} - \bar{X}_{current}\right) + t_{\left(1-\left(\frac{\alpha}{2}\right),(V)\right)} S_p \left(\left(\frac{1}{n_{previous}}\right) + \left(\frac{1}{n_{current}}\right)\right)^2}{f} \ldots\ldots (7)$$

Where,

f =time interval for $t_{previous}$ and $t_{current}$.

S_p=unbiased estimator under the assumption of $\sigma^2_{Previous} = \sigma^2_{current}$ which can be expressed as

$$S_p = \frac{\left(n_{previous} - 1\right)\hat{S}^2_{Previous} + \left(n_{current} - 1\right)\hat{S}^2_{current}}{n_{previous} - 1 + n_{current} - 1}$$

$t_{\left(1-\left(\frac{\alpha}{2}\right),(V)\right)}$= t-value corresponding to Student`s t distribution.

α= Confidence level (%)

For the applications to site piping spools, there are few steps to achieve the corrosion rate which is (Chi Hui Chien, 2008):

1. Pre-select the thickness measurement locations on the pressure components where thinning conditions are suspected (refer to the API RP 574)
2. Perform the ultrasonic thickness survey on the selected thickness measurement locations of the pressure components.
3. Calculate the mean values of the previous survey respectively
4. Calculate the statistical parameters
5. Choose the acceptable confidence level α,1- α, and the t-value corresponds to the Student`s t distribution.
6. Substitution of the value to the equation 7
7. Substitute the inspection time interval in years
8. Collect upper limit of the corrosion rate interval in equation 7.

9. Organise the data distribution by determining the number of class using Sturge`s Rule
   $k = 1 + 3.322(log_{10}N)$
   k= number of class,
   n=size of the class.

2.3 Case study

This project involves the case study 1 and case study 2 which can be obtain from Chi Hui Chien research paper at 2008.

2.3.1 Case Study 1(Chi Hui Chien, 2008)

The aim of this case study is to determine the corrosion rate based on the data given. The data given is as below:

Table 2.1: Case Study 1 Data

Thickness measurement location	Measured data							
	Inspection date: July 2,1993				Inspection date: November 9, 2003			
	Thickness (mm)				Thickness (mm)			
	R1	R2	R3	R4	R1	R2	R3	R4
#1	6	6.3	6.1	6	5.8	5.6	5.6	5.7
#2	6.2	6.5	6.4	5.9	5.9	5.8	5.9	5.8
#3	6.2	6.5	6.3	6.4	5.3	5.4	5.2	5
#4	4.9	5.2	5	5.1	5.3	5.3	5.3	5.2
#5	5.7	6.3	6	6.1	5.3	5.4	5.4	5.5
#6	6	6.4	6.2	6.3	5.6	5.4	5.4	5.5
#7	5.1	5.4	5.2	5.3	5.2	5.2	5.1	5.1
#8	5.7	6.2	5.8	6	5.7	5.8	5.8	5.9
#9	5.7	6.2	5.8	6	5.9	5.8	5.9	5.9
#10	4.9	5.3	5	5.2	5.2	5.3	5.3	5.3

#11	6.1	6.4	6.2	6.3	5.9	5.9	5.8	5.8
#12	4.9	5.3	5	5.2	5.4	5.3	5.3	5.2
#13	5.9	6.2	6	6.2	5.2	5.3	5.3	5.2
#14	5.8	6.2	5.9	6.1	5.6	5.6	5.7	5.7
#15	4.9	5.4	5.2	5.3	5.4	5.3	5.4	5.3
#16	5.1	5.9	5.3	5.5	5.4	5.3	5.3	5.4
#17	5.8	6.1	5.9	5.6	5.5	5.6	5.6	5.6
#18	4.9	5.4	5	5.2	5.3	5.2	5.3	5.3
#19	5.9	6.1	6	6.1	5.1	5.2	5.5	5.4
#20	4.8	5.3	5	5.2	5.1	5.2	5	5.2

2.3.2 Case study 2 (Chi Hui Chien, 2008)

Second case study is conducted to further understanding about the corrosion rate of the piping spools in petroleum process. The data of the case study is illustrated as below:

Table 2.2: Case Study 2 Data

Thickness measurement location	Measured data							
	Inspection date: October 14, 2001				Inspection date: November 3, 2003			
	Thickness (mm)				Thickness (mm)			
	R1	R2	R3	R4	R1	R2	R3	R4
#1	8.2	8.4	8.3	8.4	8.2	8.4	8.8	8.5
#2	7.8	8	7.9	8	8.1	8	8.1	8.1
#3	8.1	8.5	8.2	8.4	8.4	8.5	8.7	8.6
#4	8.6	8.7	8.6	8.7	8.2	8.7	8.8	8.7
#5	7.3	7.9	7.5	7.8	8	8	8	8.1
#6	8	8.5	8.3	8.4	7.7	7.4	7.7	8.6
#7	7.8	8.4	7.9	8.2	8.2	8.1	8.1	8.2
#8	8.1	8.2	8.1	8.1	8.2	8.4	8.6	8.4
#9	7.4	8.6	7.5	8.4	7.7	8.6	7.2	7.6

2.3.3 Comparisons using both methodologies on case study 1 location #4

As an example, based on the case study 1 which is at location #4, the calculation using equation 2, corrosion rate using conventional methodology is as follows:

$$corrosion\ rate = \frac{t_{previous} - t_{current}}{time\ (years) between\ t_{previous}\ and\ t_{current}}$$

$$corrosion\ rate = \frac{5.05 - 5.275}{10.533} = -0.0213\ mm/year$$

Based on the conventional methodology, the corrosion rate at location #4 is -0.0213mm/year. The result is unreasonable due to the negative value of corrosion rate.

By using the statistical methodology on the same sample case study which is case study 1 location #4, the calculation on corrosion rate, using equation 7 is as follows:

$$\frac{(\bar{X}_{previous} - \bar{X}_{current}) - t_{(1-(\frac{\alpha}{2}),(V)} S_p \left(\left(\frac{1}{n_{previous}}\right) + \left(\frac{1}{n_{current}}\right)\right)^2}{f}$$
$$\leq \frac{\mu_{previous} - \mu_{current}}{f}$$
$$\leq \frac{(\bar{X}_{previous} - \bar{X}_{current}) + t_{(1-(\frac{\alpha}{2}),(V)} S_p \left(\left(\frac{1}{n_{previous}}\right) + \left(\frac{1}{n_{current}}\right)\right)^2}{f}$$

The $t_{(1-(\frac{\alpha}{2}),(V)}$ value is 95% by referring the t-Distribution critical value table. (Appendix 1)

$$\frac{-0.452mm}{10.533year} \leq \frac{\mu_{previous} - \mu_{current}}{f} \leq \frac{0.00431mm}{10.533year}$$

The upper limit is chosen. Hence, the corrosion rates for case study 1 at location 0.00431 mm/year. Compare to the conventional method, the statistical method is recommended as a tool for the inspector to assess the corrosion rate as it is more conservative approach compare to the conventional methodology.

Chi Hui Chen in 2008 has claimed that based on the proven result, the statistical methodology has appear to be more conservative approach in assessing the thickness data measurement of the piping system and thus estimating the corrosion rate. The result has shown that by adopting the statistical methodology model, all corrosion rates at their respective location has a positive value, compare to the conventional methodology which has certain location has negative values. In order to have a better view of the research result, he has constructed the histogram on the corrosion rate distribution as below:

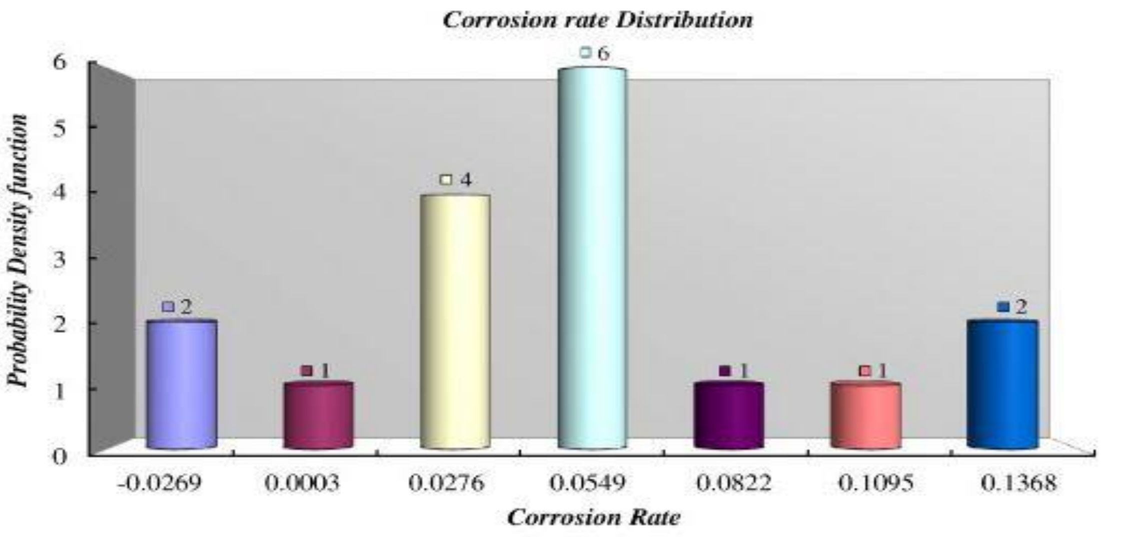

Fig. 7.

Corrosion rate histogram of a lubricant rerun unit (using conventional approach).

Figure 2.1: Corrosion rate Distribution using conventional

approach by Chi Hui Chen at 2008

As found in the above research result, by using the conventional approach, the case study has two negative values which has a corrosion rate which have upper limit of -0.0269 mm/year. The other location is as distributed accordingly to their range classes.

Furthermore, he also has conducted a research on the statistical approach using the same case study which being used in the conventional methodology. In order to show the comparison as one of the research objectives, the histogram of corrosion rate distribution has constructed as below:

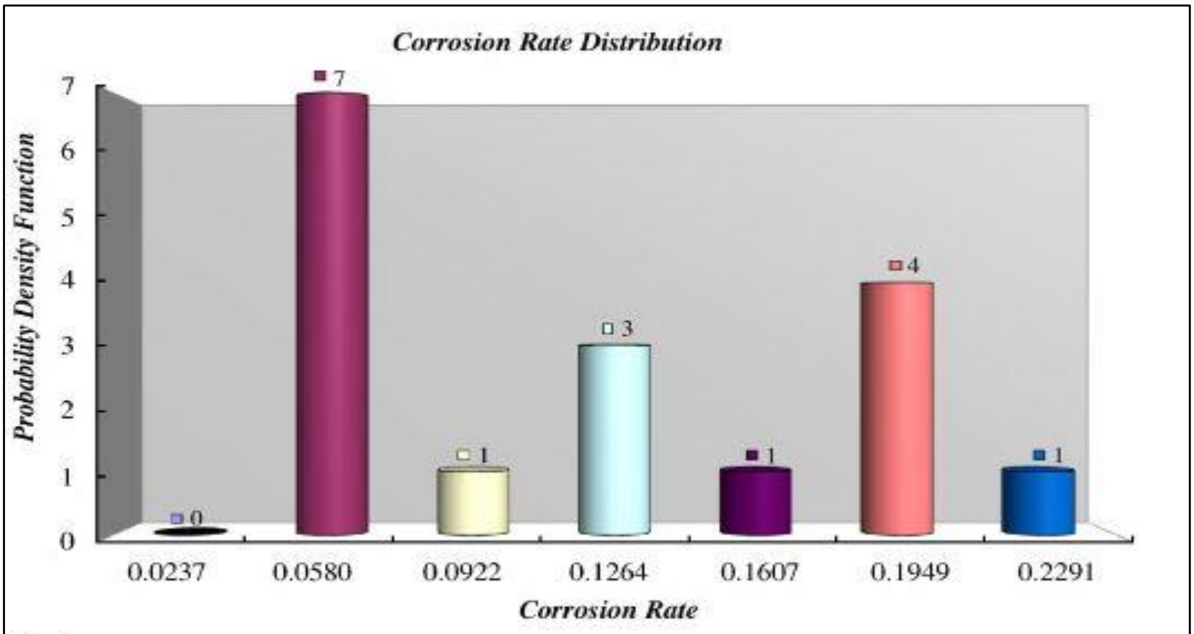

Fig. 8.
Corrosion rate histogram of a lubricant rerun unit (using statistical approach).

Figure 2.2 : Corrosion rate Distribution using

statistical approach by Chi Hui Chen at 2008

It is shown that by using the statistical methodology, the case study has no negative values. Hence, the statistical approach has claimed to be more conservative approach compare to the conventional approach.

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CHAPTER 3

METHODOLOGY/PROJECT WORK

3 METHODOLOGY

In this section, the author will discuss and highlight about the project activities by displaying the Gantt chart of FYP1, FYP2, tools required and flowchart of the project.

3.1 Gantt chart and key milestone for FYP1

Table 3.1: Gantt chart and Key milestone for FYP1 period

Detail / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Selection of Project Topic														
Preliminary Research Work • Consulting with assigned supervisor • Conducting the literature review and case study • Identifying the Problem Statement, Objectives and Scope of Study														
Submission of Extended Proposal						●								
Proposal Defence														
Continuation of Project work • Further research on the *conventional methodology* in determining the corrosion rate, thickness required and remaining life. • Further research on the *statistical methodology* by understanding the applicable Student`s *t* distribution for corrosion rate (Yan, 2002).														
Continuation of Project work • Recommend the best														

approach • Applying the method in determining the corrosion rate with the data given by assess both methodology.														
Submission of Interim Report														●

3.2 Gantt chart and key milestone for FYP2

Table 3.2 : Gantt chart and key milestone for FYP 2 period

Detail / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Preliminary Research Work • Review each case study thoroughly															
Research Work • Determining the corrosion rate by using the conventional methodology • Establish a EXCELL based simulation modelling for several method using conventional methodology															
Research Work • Revise the result data for case study 1															
Submission of Progress Report								●							
Project Work Continues • Determining the corrosion rate by using the statistical methodology															
Project Work Continues • Establish a EXCELL based simulation modelling for several method using statistical methodology															
Project Work Continues • Revise the result data for case study 2 • Propose the best method with proven result.															

Pre SEDEX											●				
Submission of Draft Report												●			
Submission of Dissertation (soft bound)													●		
Submission of Technical Paper													●		
Oral Presentation														●	
Submission of Dissertation (hard bound)															●

(dark blue)	Mid-semester Break
(pink)	Process
●	Key milestone

3.3 Tools required.

To illustrate the corrosion rate based on statistical methodology, the Microsoft Excel is required.

3.4 Research Methodology

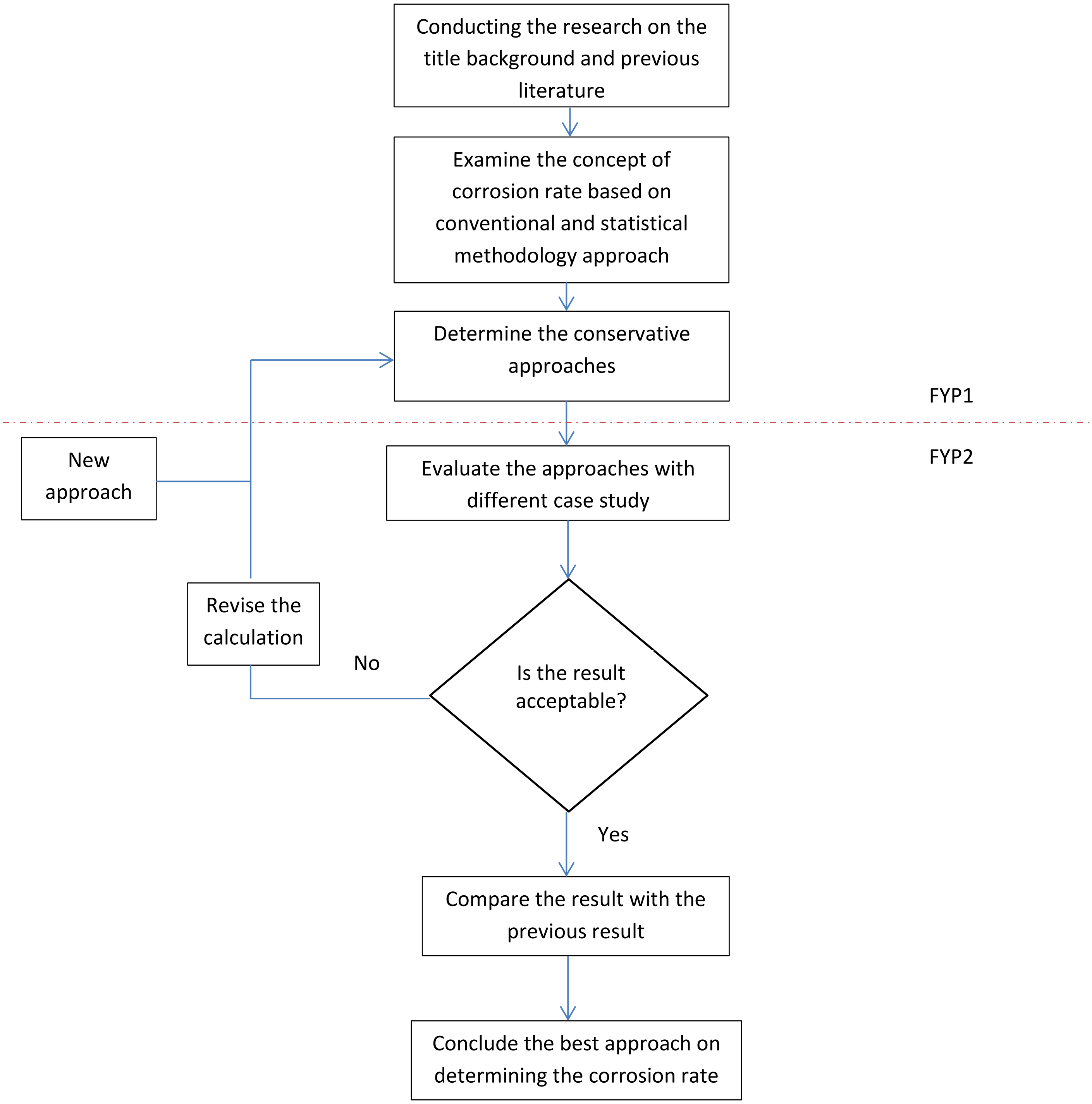

Figure 3.1 : Research Methodology

Based on the Figure 3.1, at the early stage of period FYP 1, the author has done several studies on the corrosion rate. During this period, the author has recognised the standard of pipe based on ASME B31 and API. Based on the standard, the author has recognised the search about the corrosion rate. Furthermore, during this phase, the author has searched other research material regarding the corrosion rate and their method. Next, phase is to examine the corrosion rate using the conventional and statistical approach. During this phase, the author has study several research on model in obtaining the corrosion rate. The author also discovers the mathematical path on statistical and conventional models. Proceed, during the end of period FYP1, the author has chosen the expected models that is more reliable and conservative to obtain the corrosion rate based on other approaches that the author has studies.

At the beginning of FYP2 period, the author evaluates the approaches by adopting the case study 1 and case study 2 towards the models established. The author has conduct the comparisons on the result obtain. Next is to determine whether the result of both approaches is acceptable in term of the model calculation and concept. With the discussion with the superior regarding the matter, the result is acceptable. Then, the author discuss the result obtain and revise the data by comparing the case study 1 and case study 2. By the end of period FYP2, the author has concluded the research by recommending the model with acceptable reason and application in real world.

CHAPETR 4
RESULT AND DISCUSSION

4. RESULT AND DISCUSSION

4.1 Case study 1 simulation result

Based on this case study, there are twenty location of the pipe that being measured as such the thickness using ultrasonic according to the API (1998). The inspector conducted two inspections on different time. The first inspection measurement thickness of pipe began on 2nd of July 1993 and the second inspection on 9th November 2003. Hence, the time interval for $t_{previous}$ and $t_{current}$ is approximately 10 years. The exact thickness of the respective location and the average thickness are as shown in table below:

Table 4.1: Case Study 1 Data and average thickness

Thickness measurement location	Measured data									
	Inspection date: July 2,1993					Inspection date: November 9, 2003				
	Thickness (mm)					Thickness (mm)				
	R1	R2	R3	R4	Mean thickness of R_1, R_2, R_3 and R_4	R1	R2	R3	R4	Mean thickness of R_1, R_2, R_3 and R_4
#1	6	6.3	6.1	6	6.1	5.8	5.6	5.6	5.7	5.675
#2	6.2	6.5	6.4	5.9	6.25	5.9	5.8	5.9	5.8	5.85
#3	6.2	6.5	6.3	6.4	6.35	5.3	5.4	5.2	5	5.225
#4	4.9	5.2	5	5.1	5.05	5.3	5.3	5.3	5.2	5.275
#5	5.7	6.3	6	6.1	6.025	5.3	5.4	5.4	5.5	5.4
#6	6	6.4	6.2	6.3	6.225	5.6	5.4	5.4	5.5	5.475
#7	5.1	5.4	5.2	5.3	5.25	5.2	5.2	5.1	5.1	5.15
#8	5.7	6.2	5.8	6	5.925	5.7	5.8	5.8	5.9	5.8

#9	5.7	6.2	5.8	6	5.925	5.9	5.8	5.9	5.9	5.875
#10	4.9	5.3	5	5.2	5.1	5.2	5.3	5.3	5.3	5.275
#11	6.1	6.4	6.2	6.3	6.25	5.9	5.9	5.8	5.8	5.85
#12	4.9	5.3	5	5.2	5.1	5.4	5.3	5.3	5.2	5.3
#13	5.9	6.2	6	6.2	6.075	5.2	5.3	5.3	5.2	5.25
#14	5.8	6.2	5.9	6.1	6.025	5.6	5.6	5.7	5.7	5.65
#15	4.9	5.4	5.2	5.3	5.2	5.4	5.3	5.4	5.3	5.35
#16	5.1	5.9	5.3	5.5	5.45	5.4	5.3	5.3	5.4	5.35
#17	5.8	6.1	5.9	5.6	5.85	5.5	5.6	5.6	5.6	5.575
#18	4.9	5.4	5	5.2	5.125	5.3	5.2	5.3	5.3	5.275
#19	5.9	6.1	6	6.1	6.025	5.1	5.2	5.5	5.4	5.3
#20	4.8	5.3	5	5.2	5.075	5.1	5.2	5	5.2	5.125

The summary for the case study is illustrated in graph as below:

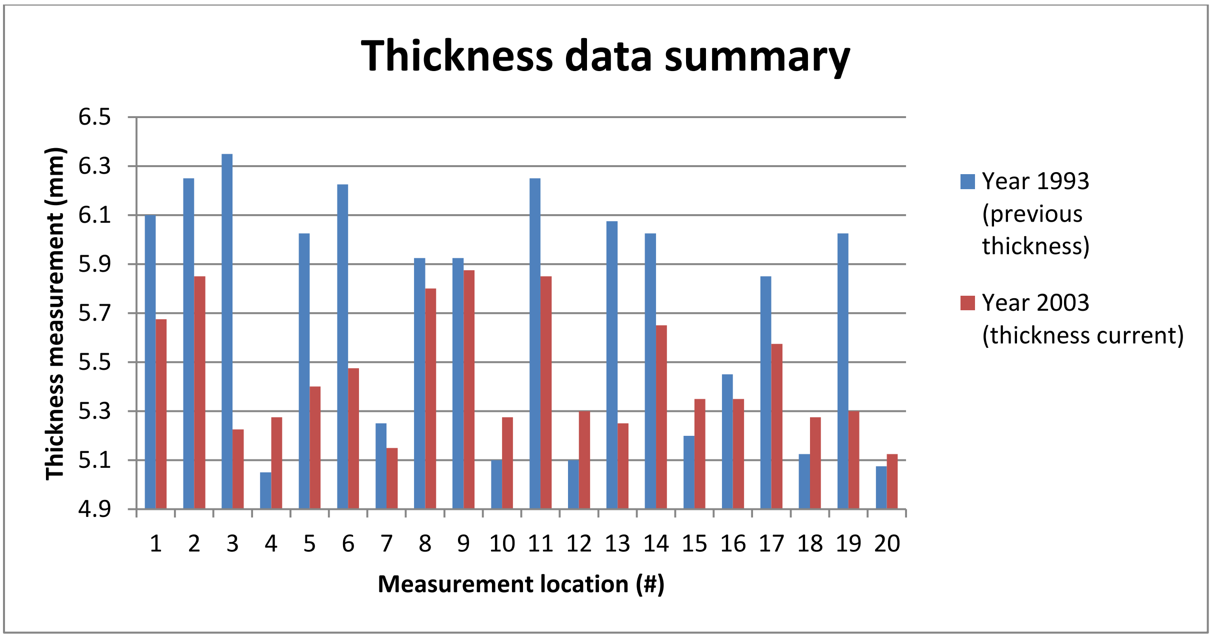

Figure 4.1: Case study 1 thickness data summary

The R_n are the reading of the ultrasonic measurement at specific location. The mean thickness of R_1, R_2, R_3 *and* R_4 is calculated as below:

$$\frac{R_1 + R_2 + R_3 + R_3}{4} = Mean\ thickness\ of R_1, R_2, R_3\ and\ R_4 \dots \dots \dots \dots \dots (4)$$

For location 1 (#1), the calculation is as below:

$$\frac{6 + 6.3 + 6.1 + 6}{4} = 6.1$$

Other location thickness mean measurement data is further calculated.

The result for the 1st case study is assessed. Unfortunately, based on the graph 1 above, the location at #4, #10, #12, #15, #18 and #20, the $t_{current}$ is higher than $t_{previous}$. Hence, based on equation 2, the corrosion rate has a negative value. Theoretically, the $t_{previous}$ should be higher than the $t_{current}$ in order for the corrosion to take place. Hence, the corrosion rate can be determined. The overall mean thickness including all the 20 location, the graph below is illustrated.

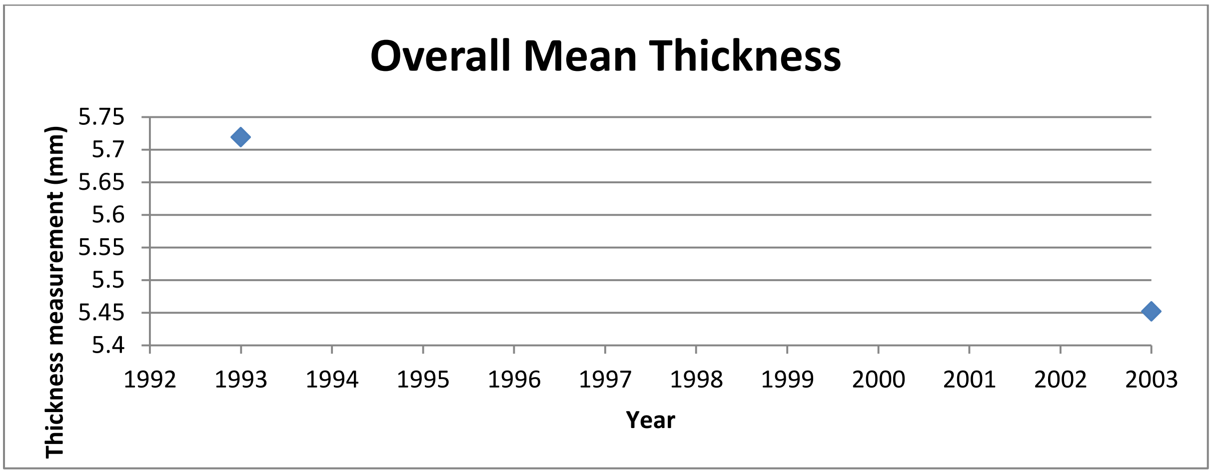

Figure 4.2 : Case study 1 overall mean thickness

To examine the corrosion rate of the case study, the conventional and statistical approach is adopted.

4.1.1 Case study 1 simulation result (conventional methodology)

The corrosion rate of each respective location using the conventional approach is illustrated in table as below:

Table 4.2: Corrosion rate of case study 1 using conventional approach

Conventional Approach (Case Study 1)	
Location	Corrosion rate(mm/year)
#1	0.04045
#2	0.03808
#3	0.10709
#4	-0.02142
#5	0.05949
#6	0.07139
#7	0.00952
#8	0.01190
#9	0.00476
#10	-0.01666
#11	0.03808
#12	-0.01904
#13	0.07853
#14	0.03332
#15	-0.01428
#16	0.00952
#17	0.02618
#18	-0.01428
#19	0.06901
#20	-0.00476

To gain a better view of the result data obtain based on the case study for conventional methodology in estimating corrosion rate; the bar chart is illustrated as below:

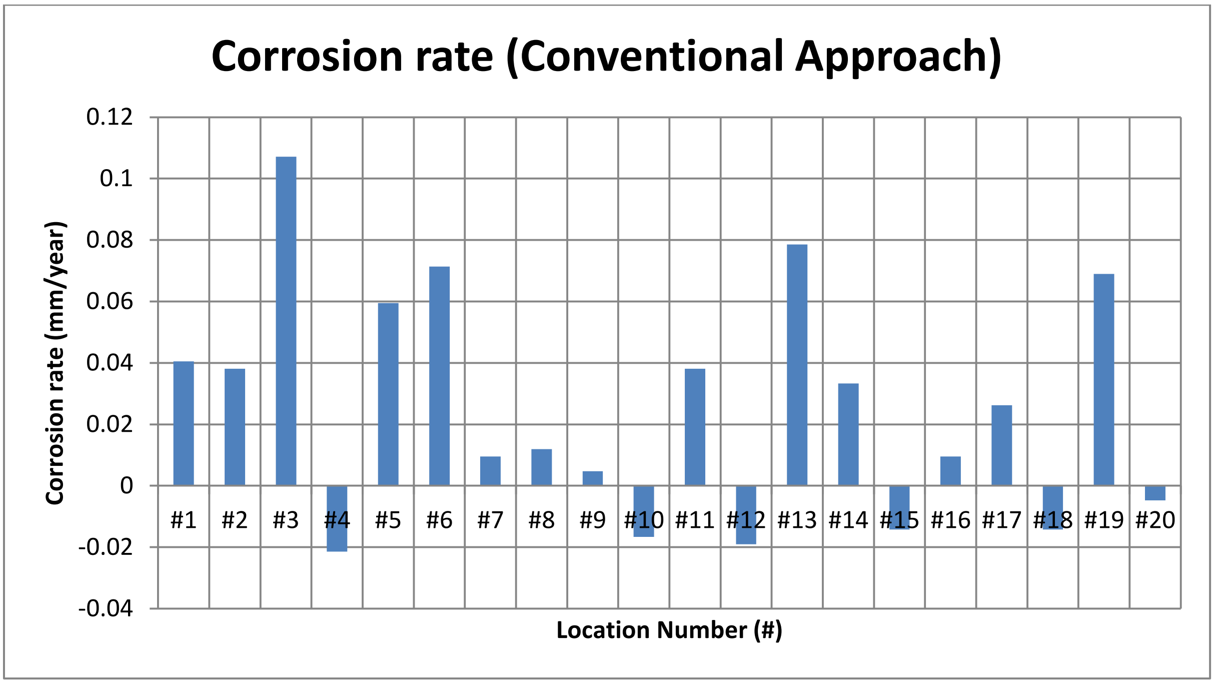

Figure 4.3: Histogram of corrosion rate of case study 1 using conventional approach

It is observed that the location #4, #10, #12, #15, #18 and #20 for conventional approaches is negative value. Hence, these location corrosion rate is unable to determine due to the unreasonable value which shown to be denying the nature of corrosion phenomenon .The highest value of the corrosion rate (mm/year) is at the location #3 which is 0.1070mm/year followed by location #13, #6 and #19 which is 0.07852mm/year, 0.07139mm/year and 0.06901mm/year respectively. On the other hand, the lowest value of the corrosion rate is at location #9 which is 0.004759mm/year followed by location #7 which has corrosion rate of 0.009518mm/year which is the second lowest of the corrosion rate value. Next is location #8 which is 0.01189mm/year as the third lowest corrosion rate.

4.1.2 Case study 1 simulation result (statistical methodology)

The corrosion rate of each respective location using the statistical approach is illustrated in table as below:

Table 4.3: Corrosion rate of case study 1 using statistical approach

Statistical Approach (Case Study 1)		
Thickness Measurement Location	Unbiased Estimator	Corrosion Rate at respective confidence level (mm/year)
#1	0.01458	0.061024
#2	0.03667	0.057993
#3	0.02292	0.126818
#4	0.00958	-0.02136
#5	0.03458	0.069354
#6	0.01917	0.091214
#7	0.01000	0.039499
#8	0.02792	0.014881
#9	0.02583	0.005759
#10	0.01344	-0.01661
#11	0.00750	0.057979
#12	0.01500	-0.01898
#13	0.00969	0.09833
#14	0.01375	0.043235
#15	0.01875	-0.01423
#16	0.04500	0.009615
#17	0.01719	0.027117
#18	0.01938	-0.01423

#19	0.01594	0.078839
#20	0.02188	-0.00474

To gain a better view of the summarise result data obtain based on case study 1 for statistical methodology in estimating the corrosion rate, the bar chart is illustrated as below:

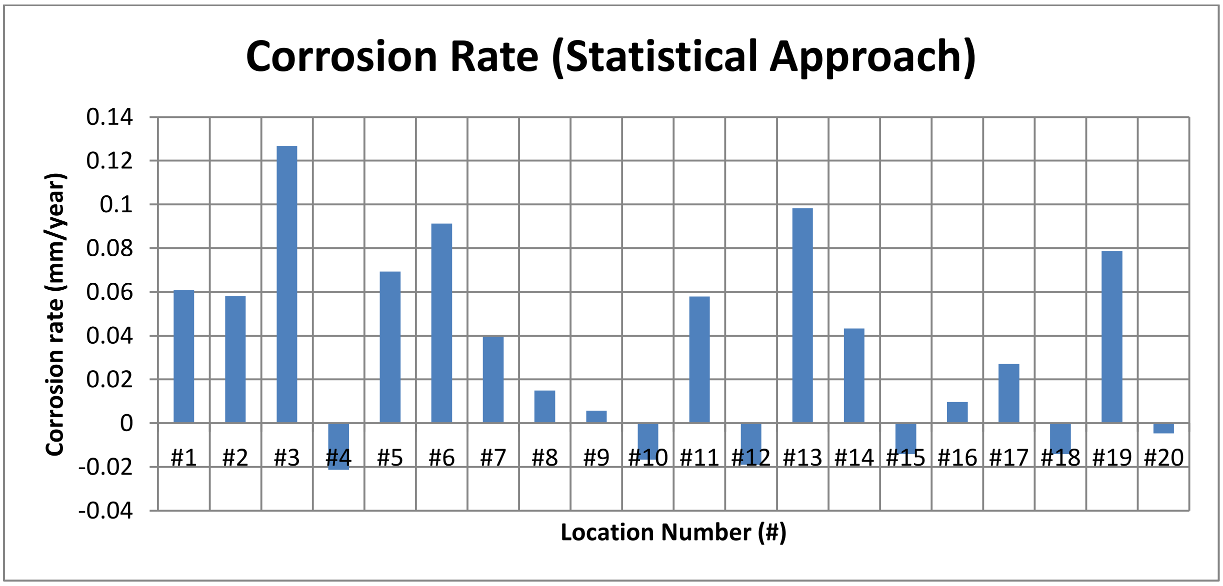

Figure 4.4: Histogram of corrosion rate of case study 1 using statistical approach

It is observed that the location #4, #10, #12, #15, #18 and #20 for conventional approaches is negative value. Hence, these location corrosion rate is unable to determine due to the unreasonable value which shown to be denying the nature of corrosion phenomenon .The highest value of the corrosion rate (mm/year) is at the location #3 which is 0.1268 mm/year followed by location #13, #6 and #19 which is 0.09832 mm/year, 0.09121mm/year and 0.07883mm/year respectively. On the other hand, the lowest value of the corrosion rate is at location #9 which is 0.004759mm/year followed by location #7 which has corrosion rate of 0.005759mm/year which is the second lowest of the corrosion rate value. Next is location #8 which is 0.01488 mm/year as the third lowest corrosion rate.

4.1.3 Case study 1 simulation result (discussion)

By applying both conventional approaches and statistical approach on case study 1, the graph can be obtained as below:

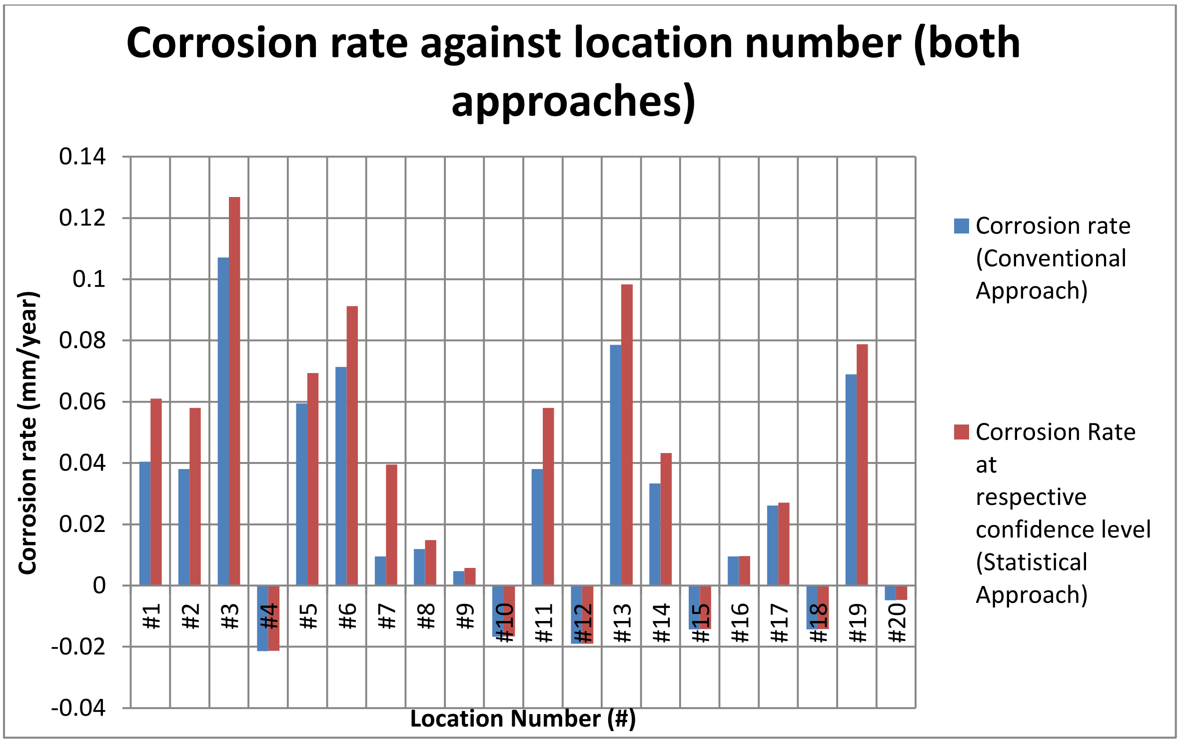

Figure 4.5 : Comparison of corrosion rate of case study 1 using both approaches

It is observed that location number #4, #10, #12, #15, #18 and #20, corrosion rate is at negative value with using both approach which is conventional methodology and statistical methodology. It seems that both methodologies cannot estimate the whole corrosion rate with respective location.

Furthermore, based on the result, most of the corrosion rate from statistical approach has a larger value compare to the corrosion rate from using the conventional approach. This may due from multiplier factors existing in statistical calculation modelling which involving the percentage confidence level and the unbiased estimator that can contribute in the corrosion rate value. Although, the corrosion rate cannot be estimated in certain location, but obtaining corrosion rate from using the statistical approach may seem to be more realistic answer as the corrosion rate is larger than the corrosion rate gain by adopting the conventional methodology.

Corrosion rate higher means the probability of metal thinning process is quicker. Thus, frequent inspection or survey need to be conducted in monitoring the metal thinning process to secure the safety condition in the plant or the respective area.

Hence, in conclusion, by adopting statistical approach to obtain the corrosion rate in this case study, the author can gain more conservative result compare to the corrosion rate using the conventional methodology as it allow a safety precaution by instructing the inspector to undergo frequent inspection and monitoring on the condition of the pipe.

In order to achieve a better understanding about the estimated corrosion rate distribution of the piping spool, the histogram of this case study based on the conventional approach is plotted as below.

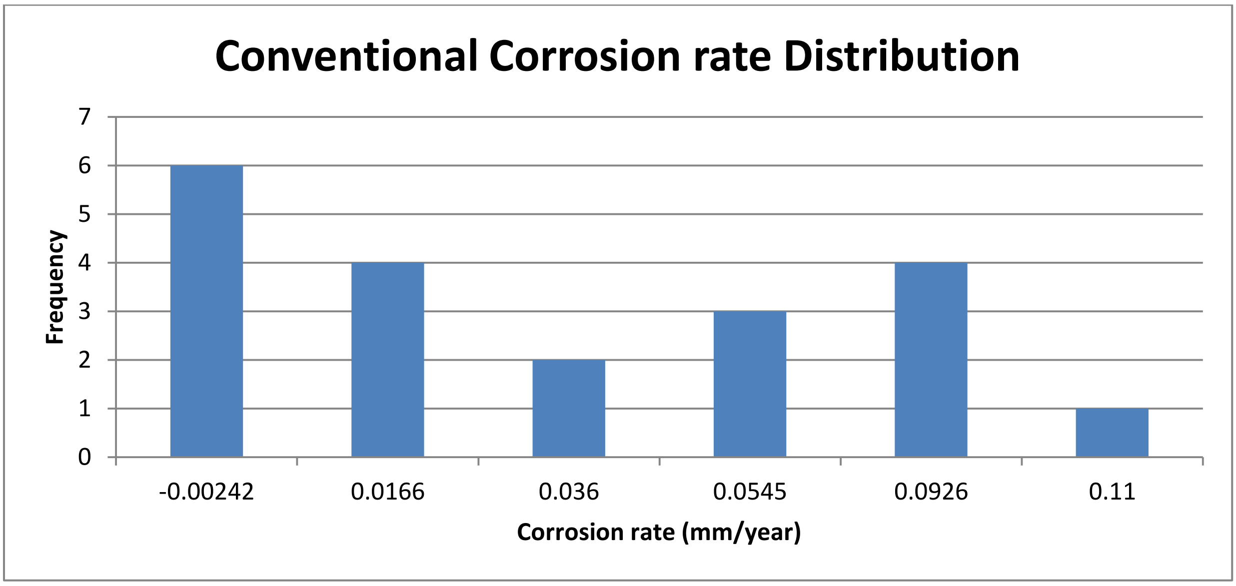

Figure 4.6 : Conventional Corrosion rate distribution of case study 1

It can be observe that the distribution of the estimated corrosion rate for most piping system in this case study for most 0.11 mm/year. However, one cannot make right inspection and maintenance strategies for piping location at #4, #10, #12, #15, #15 and #20 since their respective corrosion rate is negative values.

The histogram of the estimated corrosion rates for this case study based on the statistical approach is plotted as below.

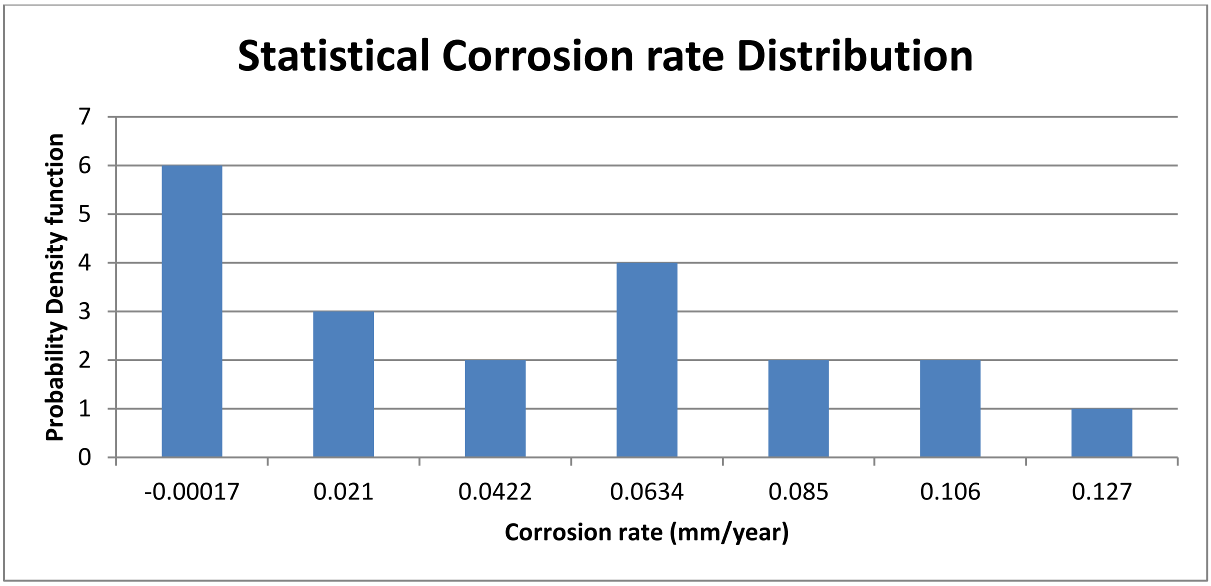

Figure 4.7: Statistical corrosion rate distribution of case study 1

It can be observe that the distribution of the estimated corrosion rate for most piping system in case study 1 for most 0.127 mm/year. However, one cannot make right inspection and maintenance strategies for piping location at #4, #10, #12, #15, #15 and #20 since their respective corrosion rate is negative values.

4.2 Case study 2 simulation result

For case study 2, the thickness measurement location is 9 locations and the sample taken is four. The previous inspection was on October 14, 2001 and the current inspection was on November 3rd, 2003. Hence, the duration between the previous and current inspection is approximately 2.08 years. The exact thickness measurement of respective location and the average thickness is shown in table below:

Table 4.4 : Case study 2 data and average thickness

Thickness measurement location	Measured data									
	Inspection date: October 14, 2001					Inspection date: November 3, 2003				
	Thickness (mm)					Thickness (mm)				
	R1	R2	R3	R4	Mean thickness	R1	R2	R3	R4	Mean thickness
#1	8.2	8.4	8.3	8.4	8.325	8.2	8.4	8.8	8.5	8.475
#2	7.8	8	7.9	8	7.925	8.1	8	8.1	8.1	8.075
#3	8.1	8.5	8.2	8.4	8.3	8.4	8.5	8.7	8.6	8.55
#4	8.6	8.7	8.6	8.7	8.65	8.2	8.7	8.8	8.7	8.6
#5	7.3	7.9	7.5	7.8	7.625	8	8	8	8.1	8.025
#6	8	8.5	8.3	8.4	8.3	7.7	7.4	7.7	8.6	7.85
#7	7.8	8.4	7.9	8.2	8.075	8.2	8.1	8.1	8.2	8.15
#8	8.1	8.2	8.1	8.1	8.125	8.2	8.4	8.6	8.4	8.4
#9	7.4	8.6	7.5	8.4	7.975	7.7	8.6	7.2	7.6	7.775

The summary for the 2nd case study is illustrated in graph as below:

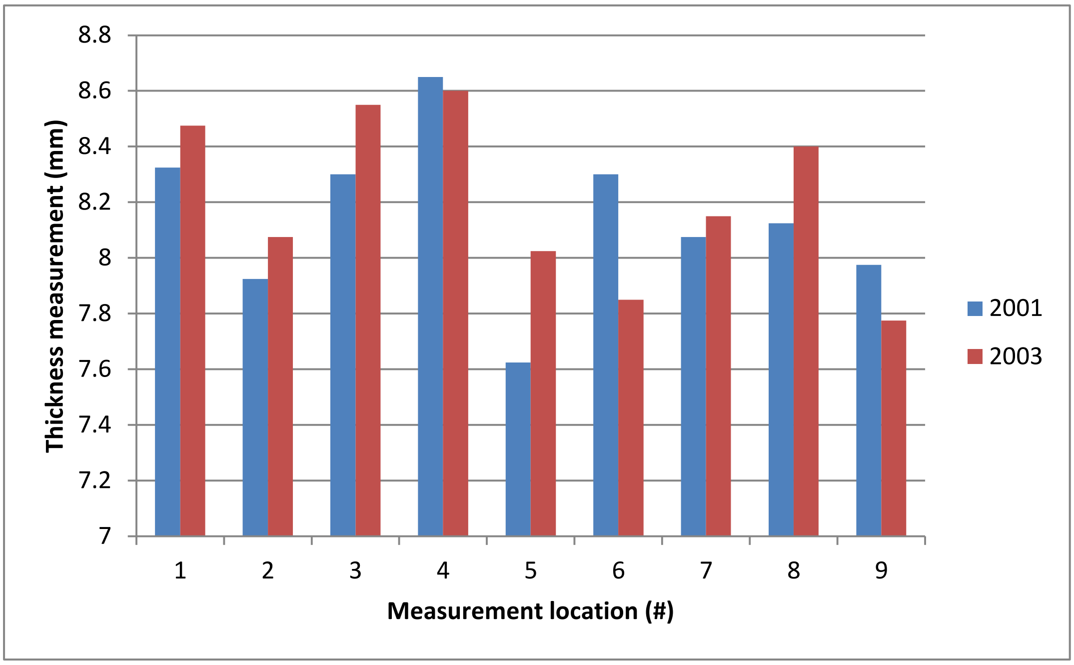

Figure 4.8 : Case study 2 thickness data summary

Based on this case study, there are nine location of the pipe that being measured the thickness using ultrasonic according to the API (1998). The inspector conducted two inspections on different date. The first inspection measurement thickness of pipe begins on 14th October of 2001 and the second inspection on 3rd November 2003. Hence, the time interval for $t_{previous}$ and $t_{current}$ is approximately 2 years. The R_n are the reading of the ultrasonic measurement at specific location. By using the equation 4, the mean thickness is calculated. Take location 1 (#1) as an example:

$$\frac{8.2 + 8.4 + 8.3 + 8.4}{4} = 8.325$$

Other location thickness mean measurement data is further calculated.

The result for the 2nd case study is assessed. Unfortunately, based on the graph 3 above, the location at #1, #2, #3, #5, #7 and #8, the $t_{current}$ is higher than $t_{previous}$. Hence, based on equation 2, the corrosion rate has a negative value. Theoretically, the $t_{previous}$ should be higher than the $t_{current}$ in order for the corrosion to take place. Hence, the corrosion rate can be determined. The overall mean thickness including all the 9 location, the graph below is illustrated as below:

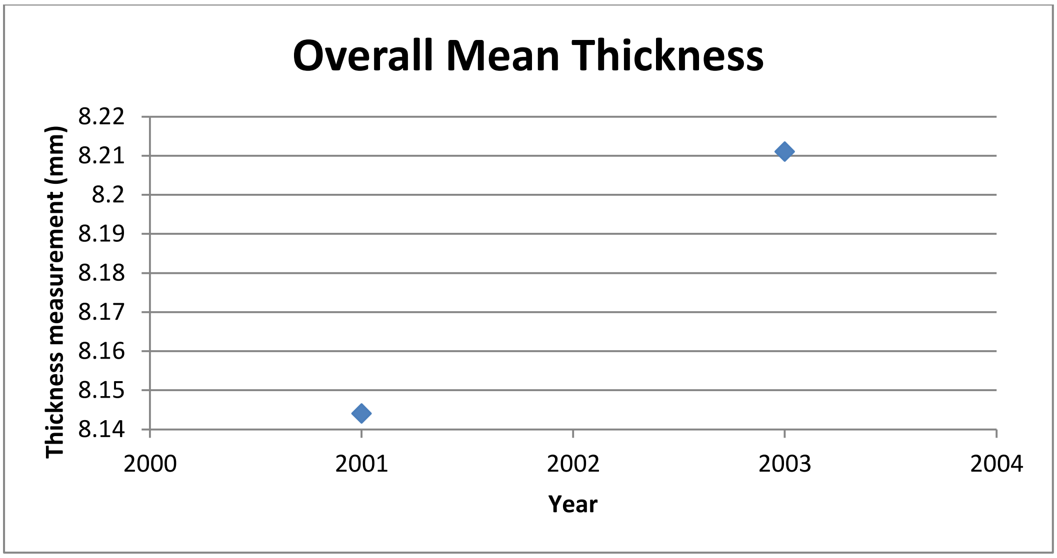

Figure 4.9 : Case study 2 overall mean thickness

In order to gain a better view of understanding on the comparison approaches for corrosion which is conventional and statistical methodology on the piping system, the histogram of the estimated corrosion rates for this case study based on the both approach is plotted as below.

4.2.1 Case study 2 simulation result (conventional methodology)

The corrosion rate of each respective location using the conventional approach is illustrated in table as below:

Table 4.5 : Corrosion rate of case study 2 using conventional approach

Conventional Approach (Case Study 2)	
Location	Corrosion rate (mm/year)
#1	-0.01428
#2	-0.01428
#3	-0.02380
#4	0.00476
#5	-0.03808
#6	0.04283
#7	-0.00714
#8	-0.02618
#9	0.01904

To gain a better view of the summarise result data obtain based on case study 2 for conventional methodology in estimating corrosion rate; the bar chart is illustrated as below:

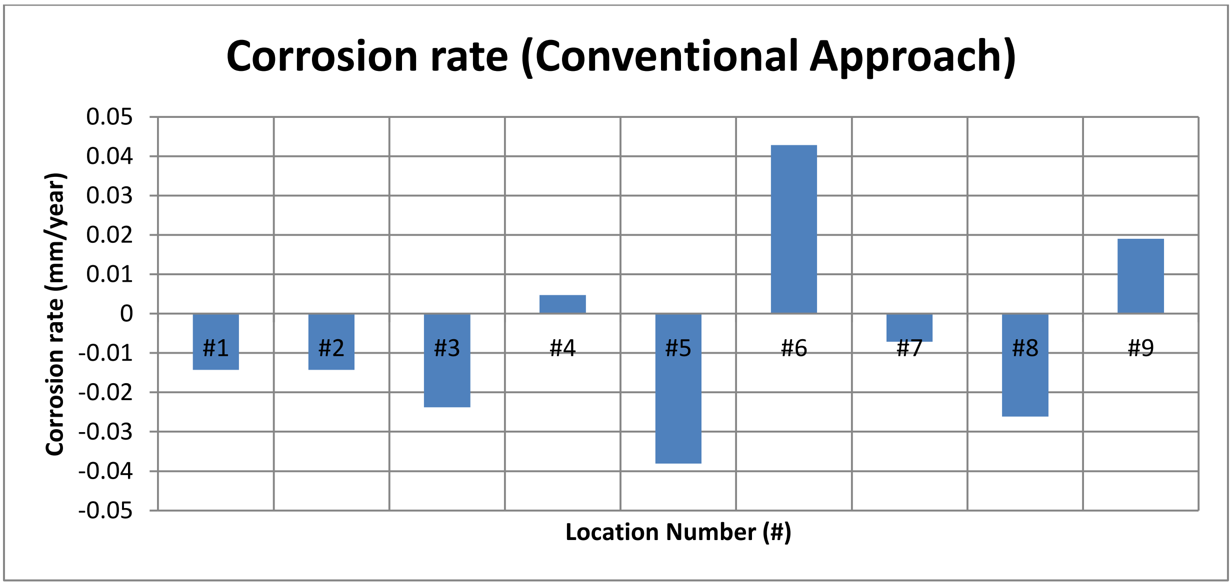

Figure 4.10: Histogram of corrosion rate of case study 2 using conventional approach

It is observed that the only location #4, #6 and #9 for conventional approaches is positive values. On the other hand, other location which is #1,#2,#3,#5,#7 and #8 corrosion rate is unable to determine due to the impossible value which shown to be defying the nature of corrosion phenomenon .The highest value of the corrosion rate (mm/year) is at the location #6 which is 0.0428 mm/year . Next is location #9 corrosion rate which is 0.019mm/year. Lastly, the lowest value of the corrosion rate is at location #4 which is 0.0048mm/year.

4.2.2 Case study 2 simulation result (statistical methodology)

The corrosion rate of each respective location using the statistical approach is illustrated in table as below:

Table 4.6: Corrosion rate of case study 2 using statistical approach

Statistical Approach (Case Study 2)		
Thickness Measurement Location	Unbiased Estimator	Corrosion Rate at respective confidence level
#1	0.03583	-0.0145
#2	0.00583	-0.0142
#3	0.02500	-0.0237
#4	0.03833	0.00567
#5	0.03917	-0.038
#6	0.15833	0.0728
#7	0.03958	-0.0071
#8	0.01458	-0.0261
#9	0.36250	0.02416

The histogram of the estimated corrosion rates for this case study based on the conventional approach is plotted as below.

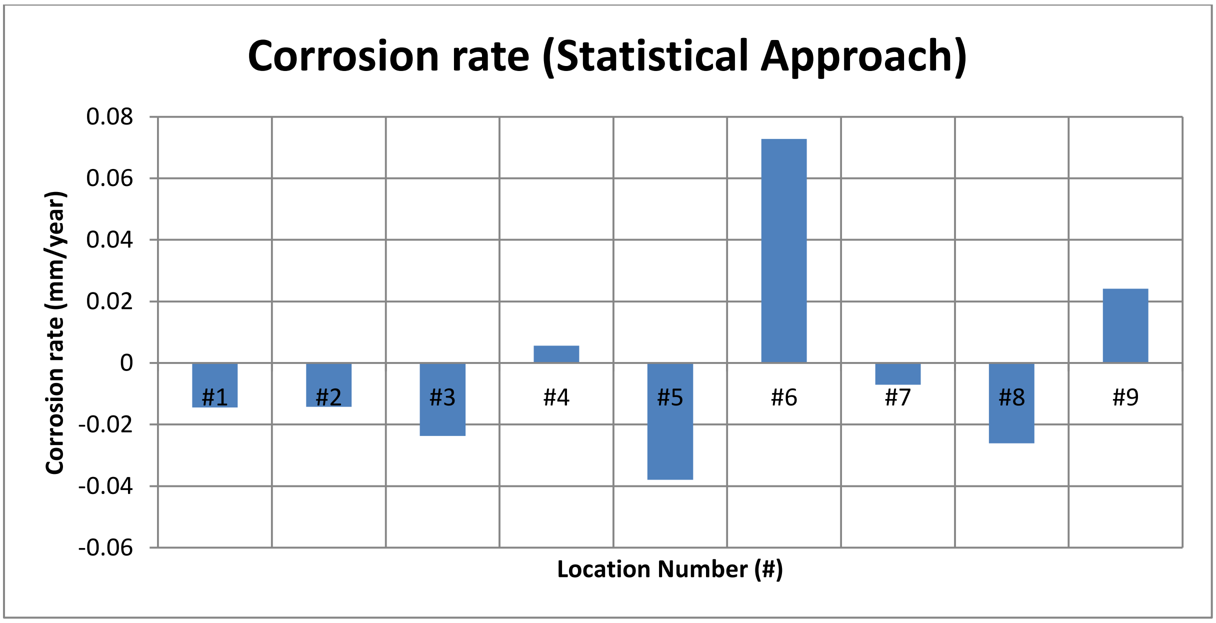

Figure 4.11: Histogram of corrosion rate of case study 2 using statistical approach

It is observed that the only location #4, #6 and #9 for conventional approaches is positive values. On the other hand, other location which is #1,#2,#3,#5,#7 and #8 corrosion rate is unable to determine due to the impossible value which shown to be defying the nature of corrosion phenomenon .The highest value of the corrosion rate (mm/year) is at the location #6 which is 0.0728 mm/year . Next is at location #9 corrosion rate which is 0.024mm/year. Lastly, the lowest value of the corrosion rate is at location #4 which is 0.00567 mm/year

4.2.3 Case study 2 simulation result (discussion)

By applying both conventional approaches and statistical approach on case study 1, the graph can be obtained as below:

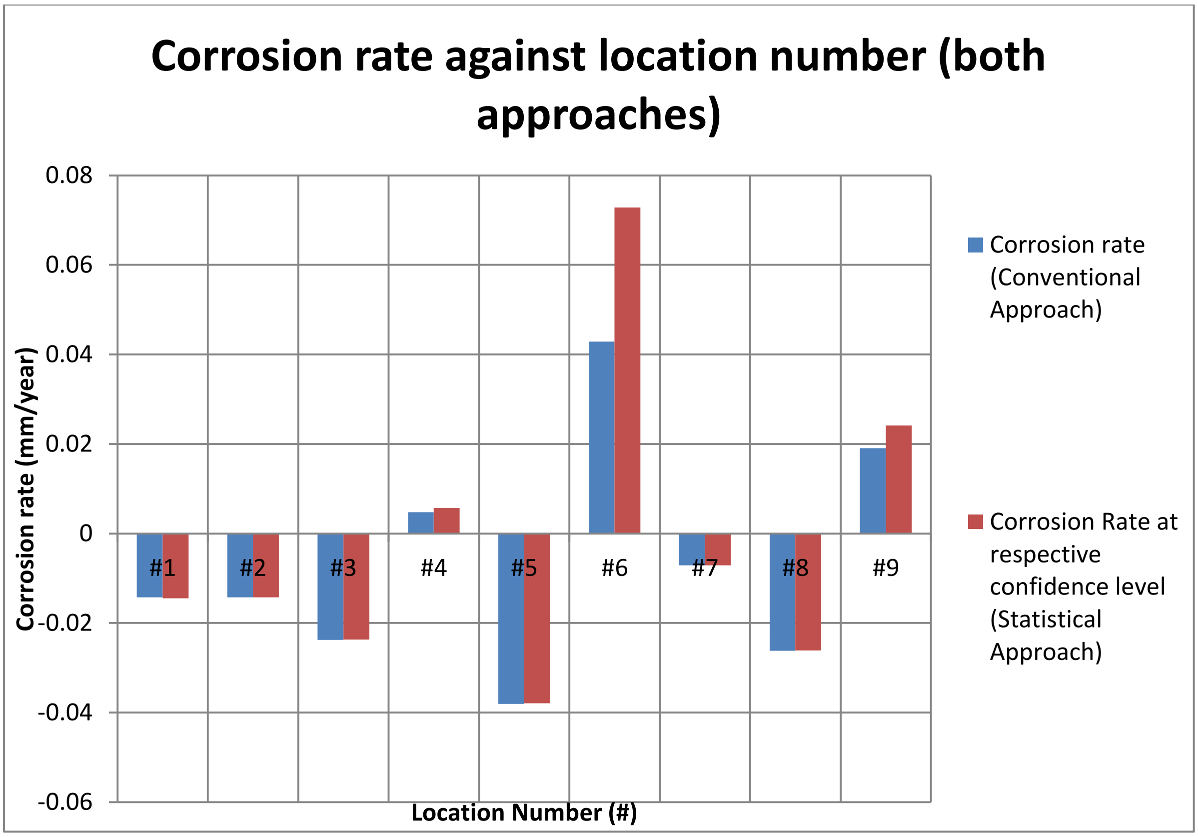

Figure 4.12: Comparison of corrosion rate of case study 2 using both approach

It is observed that location number #1, #2, #3, #5, #7 and #8, corrosion rate is at negative value with using both approach which is conventional methodology and statistical methodology. It seems that both methodologies cannot estimate the whole corrosion rate with respective location.

Furthermore, based on the result, most of the corrosion rate from statistical approach has a larger value compare to the corrosion rate from using the conventional approach. This may due from multiplier factors existing in statistical calculation modelling which involving the percentage confidence level and the unbiased estimator that can contribute in the corrosion rate value. Although, the corrosion rate cannot be estimated in certain location, but obtaining corrosion rate from using the statistical approach may seem to be more realistic answer as the corrosion rate is larger than the corrosion rate gain by adopting the conventional methodology.

Corrosion rate higher means the probability of metal thinning process is quicker. Thus, frequent inspection or survey need to be conducted in monitoring the metal thinning process to secure the safety condition in the plant or the respective area.

Hence, in conclusion, by adopting statistical approach to obtain the corrosion rate in this case study, the author can gain more conservative result compare to the corrosion rate using the conventional methodology as it allow a safety precaution by instructing the inspector to undergo frequent inspection and monitoring on the condition of the pipe.

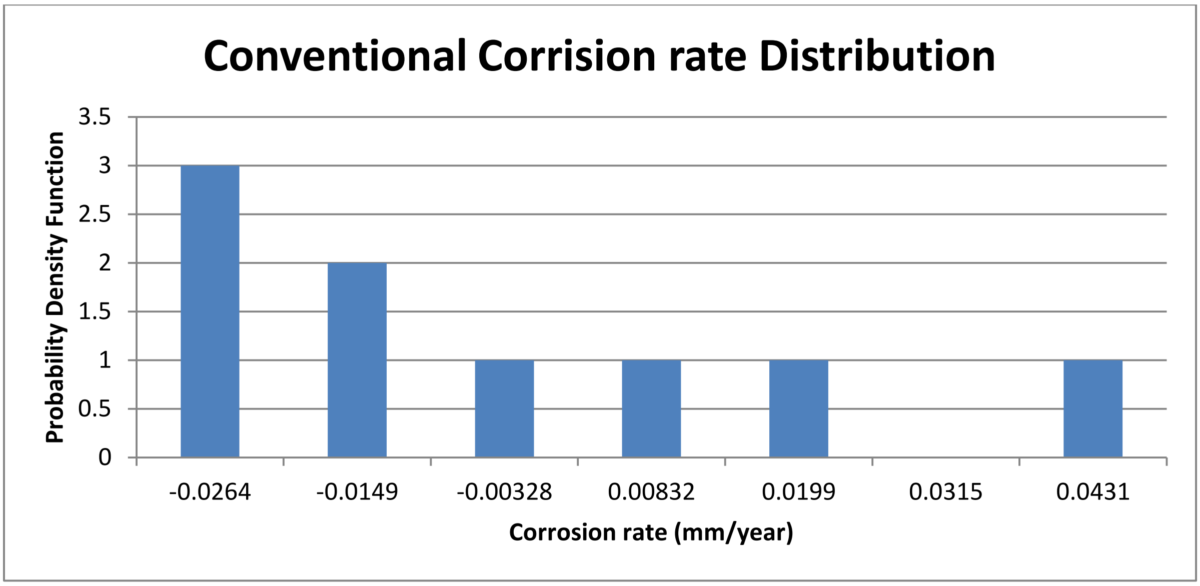

Figure 4.13 :Conventional corrosion rate distribution of case study 2

It can be found that the estimated distribution of the corrosion rate for most piping in case study 2 is on the range of 0.0037 mm/year to 0.0431 mm/year. On the contrary, one cannot make right inspection and maintenance strategies for piping location at #1, #2, #3, #5, #7 and #8 since their respective corrosion rate is negative values.

The histogram of the estimated corrosion rates for this case study based on the statistical approach is plotted as below.

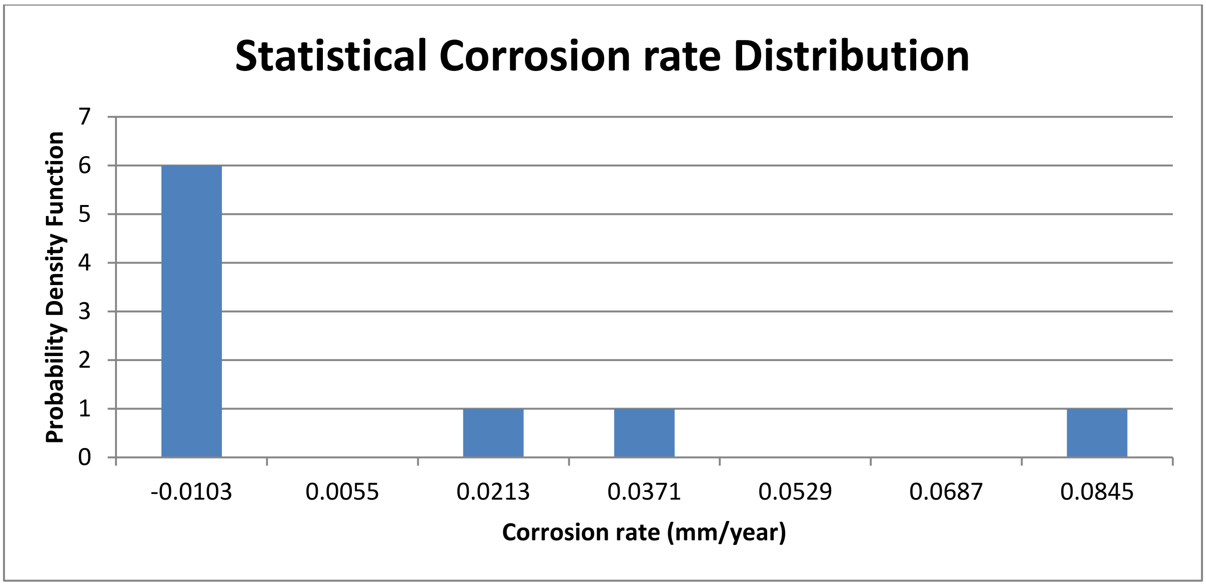

Figure 4.14 : Statistical corrosion rate distribution of case study 2

It can be found that the estimated distribution of the corrosion rate for most piping in case study 2 is on the range of 0.003 mm/year to 0.0845mm/year. On the contrary, one cannot make right inspection and maintenance strategies for piping location at #1, #2, #3, #5, #7 and #8 since their respective corrosion rate is negative values.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on the result and discussion from case study 1 and case study 2, it is confirmed with proven calculation result that the statistical methodology is more conservative than the conventional methodology. Hence, the author has proposed the statistical methodology over conventional methodology for determining the corrosion rate and hence the remaining life of the pipe.

5.2 Recommendation

Next step is to obtain another sample or case study from the supervisor to determine the corrosion rate of the piping in petroleum process using conservative approach and statistical approach. Multiples of methods need to be selected and demonstrate in obtaining a good and reasonable result from the new sample or case study given.

The recommendation proposed by the author is to broaden the research on the other statistical methodology to support the result obtain beside follow the time frame as stated in the Gantt chart of FYP 2.

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APPENDICES

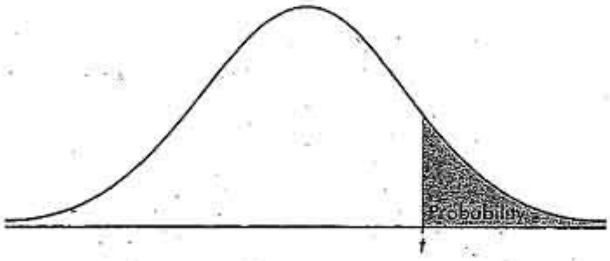

TABLE B: t-DISTRIBUTION CRITICAL VALUES

	Tail probability p											
df	.25	.20	.15	.10	.05	.025	.02	.01	.005	.0025	.001	.0005
1	1.000	1.376	1.963	3.078	6.314	12.71	15.89	31.82	63.66	127.3	318.3	636.6
2	.816	1.061	1.386	1.886	2.920	4.303	4.849	6.965	9.925	14.09	22.33	31.60
3	.765	.978	1.250	1.638	2.353	3.182	3.482	4.541	5.841	7.453	10.21	12.92
4	.741	.941	1.190	1.533	2.132	2.776	2.999	3.747	4.604	5.598	7.173	8.610
5	.727	.920	1.156	1.476	2.015	2.571	2.757	3.365	4.032	4.773	5.893	6.869
6	.718	.906	1.134	1.440	1.943	2.447	2.612	3.143	3.707	4.317	5.208	5.959
7	.711	.896	1.119	1.415	1.895	2.365	2.517	2.998	3.499	4.029	4.785	5.408
8	.706	.889	1.108	1.397	1.860	2.306	2.449	2.896	3.355	3.833	4.501	5.041
9	.703	.883	1.100	1.383	1.833	2.262	2.398	2.821	3.250	3.690	4.297	4.781
10	.700	.879	1.093	1.372	1.812	2.228	2.359	2.764	3.169	3.581	4.144	4.587
11	.697	.876	1.088	1.363	1.796	2.201	2.328	2.718	3.106	3.497	4.025	4.437
12	.695	.873	1.083	1.356	1.782	2.179	2.303	2.681	3.055	3.428	3.930	4.318
13	.694	.870	1.079	1.350	1.771	2.160	2.282	2.650	3.012	3.372	3.852	4.221
14	.692	.868	1.076	1.345	1.761	2.145	2.264	2.624	2.977	3.326	3.787	4.140
15	.691	.866	1.074	1.341	1.753	2.131	2.249	2.602	2.947	3.286	3.733	4.073
16	.690	.865	1.071	1.337	1.746	2.120	2.235	2.583	2.921	3.252	3.686	4.015
17	.689	.863	1.069	1.333	1.740	2.110	2.224	2.567	2.898	3.222	3.646	3.965
18	.688	.862	1.067	1.330	1.734	2.101	2.214	2.552	2.878	3.197	3.611	3.922
19	.688	.861	1.066	1.328	1.729	2.093	2.205	2.539	2.861	3.174	3.579	3.883
20	.687	.860	1.064	1.325	1.725	2.086	2.197	2.528	2.845	3.153	3.552	3.850
21	.686	.859	1.063	1.323	1.721	2.080	2.189	2.518	2.831	3.135	3.527	3.819
22	.686	.858	1.061	1.321	1.717	2.074	2.183	2.508	2.819	3.119	3.505	3.792
23	.685	.858	1.060	1.319	1.714	2.069	2.177	2.500	2.807	3.104	3.485	3.768
24	.685	.857	1.059	1.318	1.711	2.064	2.172	2.492	2.797	3.091	3.467	3.745
25	.684	.856	1.058	1.316	1.708	2.060	2.167	2.485	2.787	3.078	3.450	3.725
26	.684	.856	1.058	1.315	1.706	2.056	2.162	2.479	2.779	3.067	3.435	3.707
27	.684	.855	1.057	1.314	1.703	2.052	2.158	2.473	2.771	3.057	3.421	3.690
28	.683	.855	1.056	1.313	1.701	2.048	2.154	2.467	2.763	3.047	3.408	3.674
29	.683	.854	1.055	1.311	1.699	2.045	2.150	2.462	2.756	3.038	3.396	3.659
30	.683	.854	1.055	1.310	1.697	2.042	2.147	2.457	2.750	3.030	3.385	3.646
40	.681	.851	1.050	1.303	1.684	2.021	2.123	2.423	2.704	2.971	3.307	3.551
50	.679	.849	1.047	1.299	1.676	2.009	2.109	2.403	2.678	2.937	3.261	3.496
60	.679	.848	1.045	1.296	1.671	2.000	2.099	2.390	2.660	2.915	3.232	3.460
80	.678	.846	1.043	1.292	1.664	1.990	2.088	2.374	2.639	2.887	3.195	3.416
100	.677	.845	1.042	1.290	1.660	1.984	2.081	2.364	2.626	2.871	3.174	3.390
1000	.675	.842	1.037	1.282	1.646	1.962	2.056	2.330	2.581	2.813	3.098	3.300
∞	.674	.841	1.036	1.282	1.645	1.960	2.054	2.326	2.576	2.807	3.091	3.291
	50%	60%	70%	80%	90%	95%	96%	98%	99%	99.5%	99.8%	99.9%
	Confidence level C											

Appendix 1: t-distribution critical values table

Conventional Methodology

Previous Inspection:

Date of inspection (dd/mm/yy):

Thickness Measurement Location	Reading (mm) 1	Reading (mm) 2	Reading (mm) 3	Reading (mm) 4	Reading (mm) 5	Reading (mm) 6	Average Reading (mm)
#1							#DIV/0!
#2							#DIV/0!
#3							#DIV/0!
#4							#DIV/0!
#5							#DIV/0!
#6							#DIV/0!
#7							#DIV/0!
#8							#DIV/0!
#9							#DIV/0!
#10							#DIV/0!
#11							#DIV/0!
#12							#DIV/0!
#13							#DIV/0!
#14							#DIV/0!
#15							#DIV/0!
#16							#DIV/0!
#17							#DIV/0!
#18							#DIV/0!
#19							#DIV/0!
#20							#DIV/0!

Current Inspection :

Date of inspection (dd/mm/yy):

Thickness Measurement Location	Reading (mm) 1	Reading (mm) 2	Reading (mm) 3	Reading (mm) 4	Reading (mm) 5	Reading (mm) 6	Average Reading (mm)
#1							#DIV/0!
#2							#DIV/0!
#3							#DIV/0!
#4							#DIV/0!
#5							#DIV/0!
#6							#DIV/0!
#7							#DIV/0!
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#9							#DIV/0!
#10							#DIV/0!
#11							#DIV/0!
#12							#DIV/0!
#13							#DIV/0!
#14							#DIV/0!
#15							#DIV/0!
#16							#DIV/0!
#17							#DIV/0!
#18							#DIV/0!
#19							#DIV/0!
#20							#DIV/0!

Duration between Previous Inspection and Current Inspection (T):	
Internal Design Gauge Pressure (psi):	
Outside Diameter as listed in table of standards (mm):	
Allowable Stress Material Value (S):	
Quality Factor (E):	

<u>Conventional Modelling</u>

How to use this spreadsheet:

1.Enter the date of inspection for previous inspection at Cell D5.

2. In Cells B8 through G27, enter the thickness measurement data during the previous inspection conducted.

3.Enter the date of inspection for current inspection at Cell D31.

4. In Cells B34 through G53, enter the thickness measurement data during the current inspection conducted.

5. Enter the required information at Cells H55,H56,H57,H58 and H59.

6. The result for the thickness required is shown at Cell H64.

7. The corrosion rate and the remaining life at each location is shown at Cells B 66 through D 67.

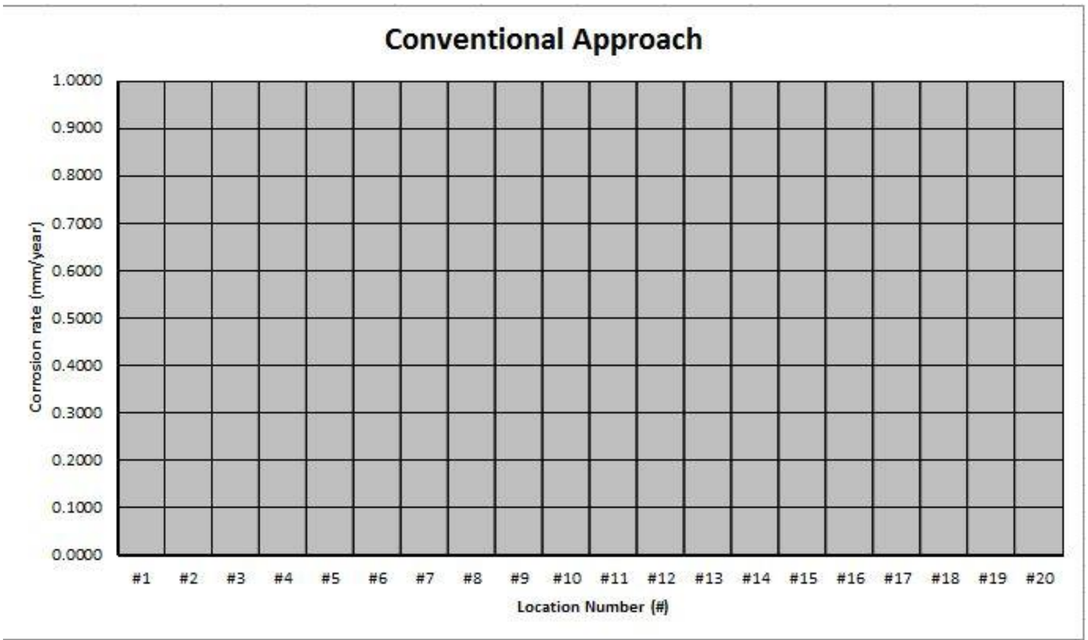
8. The histogram of corrosion rate against location number is shown.

Conventional Modelling guide

Result:

Thickness required: #DIV/0!

Location	Corrosion rate	Remaining Life
#1	#DIV/0!	#DIV/0!
#2	#DIV/0!	#DIV/0!
#3	#DIV/0!	#DIV/0!
#4	#DIV/0!	#DIV/0!
#5	#DIV/0!	#DIV/0!
#6	#DIV/0!	#DIV/0!
#7	#DIV/0!	#DIV/0!
#8	#DIV/0!	#DIV/0!
#9	#DIV/0!	#DIV/0!
#10	#DIV/0!	#DIV/0!
#11	#DIV/0!	#DIV/0!
#12	#DIV/0!	#DIV/0!
#13	#DIV/0!	#DIV/0!
#14	#DIV/0!	#DIV/0!
#15	#DIV/0!	#DIV/0!
#16	#DIV/0!	#DIV/0!
#17	#DIV/0!	#DIV/0!
#18	#DIV/0!	#DIV/0!
#19	#DIV/0!	#DIV/0!
#20	#DIV/0!	#DIV/0!



Result modelling for conventional methodology

Statistical Methodology

Previous Inspection

Date of inspection (dd/mm/yyyy):	
Number of thickness measurement taken during previous inspection :	
Number of location measured :	

Thickness Measurement Location	Reading (mm) 1	Reading (mm) 2	Reading (mm) 3	Reading (mm) 4	Reading (mm) 5	Reading (mm) 6	Average Reading (mm)	Standard Deviation	Standard Deviation ^2
#1							#DIV/0!	#DIV/0!	#DIV/0!
#2							#DIV/0!	#DIV/0!	#DIV/0!
#3							#DIV/0!	#DIV/0!	#DIV/0!
#4							#DIV/0!	#DIV/0!	#DIV/0!
#5							#DIV/0!	#DIV/0!	#DIV/0!
#6							#DIV/0!	#DIV/0!	#DIV/0!
#7							#DIV/0!	#DIV/0!	#DIV/0!
#8							#DIV/0!	#DIV/0!	#DIV/0!
#9							#DIV/0!	#DIV/0!	#DIV/0!
#10							#DIV/0!	#DIV/0!	#DIV/0!
#11							#DIV/0!	#DIV/0!	#DIV/0!
#12							#DIV/0!	#DIV/0!	#DIV/0!
#13							#DIV/0!	#DIV/0!	#DIV/0!
#14							#DIV/0!	#DIV/0!	#DIV/0!
#15							#DIV/0!	#DIV/0!	#DIV/0!
#16							#DIV/0!	#DIV/0!	#DIV/0!
#17							#DIV/0!	#DIV/0!	#DIV/0!
#18							#DIV/0!	#DIV/0!	#DIV/0!
#19							#DIV/0!	#DIV/0!	#DIV/0!
#20							#DIV/0!	#DIV/0!	#DIV/0!

Current Inspection

Date of inspection (dd/mm/yyyy):	
Number of thickness measurement taken during current inspection :	
Number of location measured :	

Thickness Measurement Location	Reading (mm) 1	Reading (mm) 2	Reading (mm) 3	Reading (mm) 4	Reading (mm) 5	Reading (mm) 6	Average Reading (mm)	Standard Deviation	Standard Deviation ^2
#1							#DIV/0!	#DIV/0!	#DIV/0!
#2							#DIV/0!	#DIV/0!	#DIV/0!
#3							#DIV/0!	#DIV/0!	#DIV/0!
#4							#DIV/0!	#DIV/0!	#DIV/0!
#5							#DIV/0!	#DIV/0!	#DIV/0!
#6							#DIV/0!	#DIV/0!	#DIV/0!
#7							#DIV/0!	#DIV/0!	#DIV/0!
#8							#DIV/0!	#DIV/0!	#DIV/0!
#9							#DIV/0!	#DIV/0!	#DIV/0!
#10							#DIV/0!	#DIV/0!	#DIV/0!
#11							#DIV/0!	#DIV/0!	#DIV/0!
#12							#DIV/0!	#DIV/0!	#DIV/0!
#13							#DIV/0!	#DIV/0!	#DIV/0!
#14							#DIV/0!	#DIV/0!	#DIV/0!
#15							#DIV/0!	#DIV/0!	#DIV/0!
#16							#DIV/0!	#DIV/0!	#DIV/0!
#17							#DIV/0!	#DIV/0!	#DIV/0!
#18							#DIV/0!	#DIV/0!	#DIV/0!
#19							#DIV/0!	#DIV/0!	#DIV/0!
#20							#DIV/0!	#DIV/0!	#DIV/0!

Period of time between previous inspection and current inpection (year):	0.00
Internal Design Gauge Pressure (psi):	
Outside Diameter as listed in table of standards (mm):	
Allowable Stress Material Value (S):	
Quality Factor (E):	

Degree of Freedom:	-2
Confidence Level (%) :	
Coefficient of multiplier with respective confidence level	0.5
Student`s t Distribution value :	#NUM!

Statistical modelling

How to use this spreadsheet:

1. Enter the date of the previous inspection at Cell I5.

2. Enter the number of thickness measurement taken during the previous inspection at Cell I6.

3. Enter the number of location measured during the previous inspection conducted at Cell I7.

4. In Cells B10 through G29, enter the thickness measurement data during the previous inspection conducted.

5. Enter the date of the current inspection at Cell I33.

6. Enter the number of thickness measurement taken during the current inspection at Cell I34.

7. Enter the number of location measured during the current inspection conducted at Cell I35.

8. In Cells B38 through G57, enter the thickness measurement data during the current inspection conducted.

9. Enter the required information at Cells J60,J61,J62 and J63.

10. Enter the confidence level in percentage(%) in Cell D66.

11. The result for the thickness required is shown at Cell J73.

12. The corrosion rate with respective confidence level and the remaining life at each location is shown at Cells B 76 through C 95.

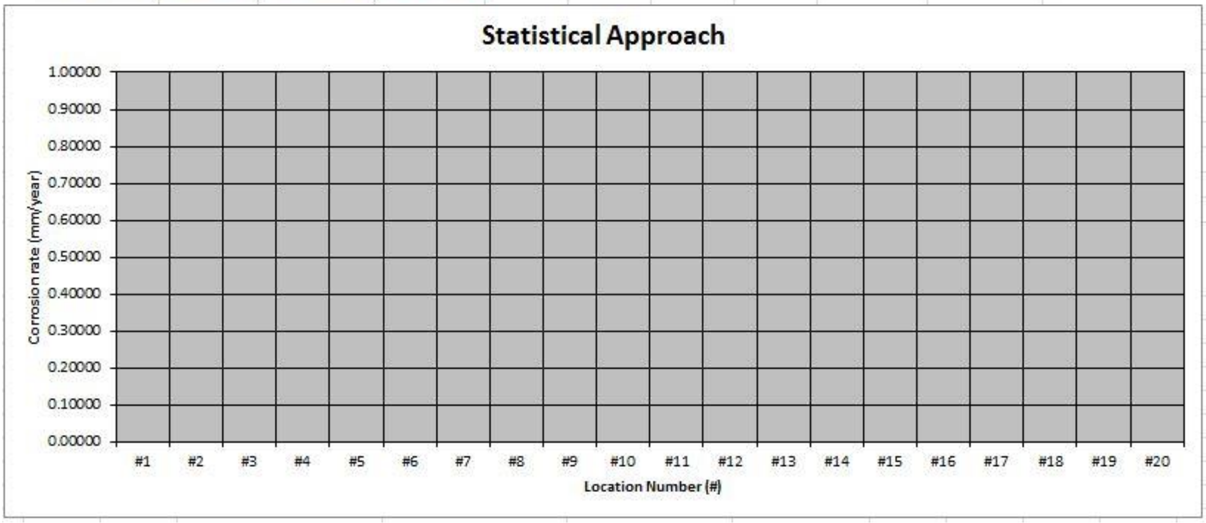
13. The histogram of corrosion rate with respective confidence level against the location number is illustrated as below.

Statistical modelling guide

Result:

Thickness required:	#DIV/0!

Thickness Measurement Location	Unbiased Estimator	Corrosion Rate at respective confidence level	Remaining life
#1	#DIV/0!	#DIV/0!	#DIV/0!
#2	#DIV/0!	#DIV/0!	#DIV/0!
#3	#DIV/0!	#DIV/0!	#DIV/0!
#4	#DIV/0!	#DIV/0!	#DIV/0!
#5	#DIV/0!	#DIV/0!	#DIV/0!
#6	#DIV/0!	#DIV/0!	#DIV/0!
#7	#DIV/0!	#DIV/0!	#DIV/0!
#8	#DIV/0!	#DIV/0!	#DIV/0!
#9	#DIV/0!	#DIV/0!	#DIV/0!
#10	#DIV/0!	#DIV/0!	#DIV/0!
#11	#DIV/0!	#DIV/0!	#DIV/0!
#12	#DIV/0!	#DIV/0!	#DIV/0!
#13	#DIV/0!	#DIV/0!	#DIV/0!
#14	#DIV/0!	#DIV/0!	#DIV/0!
#15	#DIV/0!	#DIV/0!	#DIV/0!
#16	#DIV/0!	#DIV/0!	#DIV/0!
#17	#DIV/0!	#DIV/0!	#DIV/0!
#18	#DIV/0!	#DIV/0!	#DIV/0!
#19	#DIV/0!	#DIV/0!	#DIV/0!
#20	#DIV/0!	#DIV/0!	#DIV/0!



Statistical modelling result